DUCTED FANS WITH DOWNSTREAM DIFFUSION

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DUCTED FANS WITH DOWNSTREAM DIFFUSION

D.R.M.E. Contract 27/67

Digest Report

BC/SB - 5/12/68 B. CHEZLEPRETRE

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NOTATIONS

Indices of Position (see Plate 1)

0 Infinitely upstream /3
1 Plane of the throat
2 Plane of blowing (passing through the end of the upstream lip of the diffuser)
3 Plane of exit (passing through the end of the downstream lip of the diffuser)
4 Infinitely downstream
P Plane of propeller rotation
I Internal wall of the shroud

Geometric Magnitudes

6 (subscript) Angle of the tangent to the profile in the plane considered with the axis of the model
D (subscript) Exterior diameter of inflow in the plane considered
D or D_1 Throat diameter--reference length
S (subscript) Section corresponding to the diameter D (subscript):

$$S\ (\text{subscript}) = \frac{\pi D^2\ (\text{subscript})}{4}$$

S Throat section (in the absence of a hub)--reference surface
e Thickness of the blowing slot of the shroud
s Curvilinear abscissa relative to the internal wall of the shroud measured from the entrance plane of the collector
θ Angle of incidence of the propeller profile at 0.697 D_p
Pc/D Relative pitch of the propeller at 0.7 D

Other Magnitudes

ρ Air mass per unit volume /4
ν Kinematic viscosity
n_p Mode of operation of the propeller in rps
η_p Propeller efficiency
L_p Chord of peripheral blades
R_p Peripheral Reynolds number: $R_p = \frac{\pi n_p D_p L_p}{\nu}$
V (subscript) Mean velocity in the absence of a hub in the plane considered
V_I Velocity at the internal wall of the propeller (2/3)
M'_1 Value number: $M'_1 = \frac{(\text{thrust})}{\sqrt{4 S_1}\ \text{absorbed power}}$
Cs Blowing rate:

$$Cs = \frac{\text{blowing power on the level of the slot}}{\text{power furnished to the propeller}}$$

σ_g	Geometric diffusion--jet section infinitely downstream relative to the throat section $\sigma_g = S_4/S_1$
S_3/S_1	Relative exit section of the diffuser
η'_i	Total efficiency: $N'_1 = r'_1\sqrt{\sigma_g}$
r	Air blower pressure ratio
x	Rate of dilution of the air blower system of the shroud: $x = \frac{\text{engine output + intake output}}{\text{engine output}}$
p_T (subscript)	Total pressure of a fluid stream in the plane considered
p_S	Ambient static pressure

DUCTED FANS WITH DOWNSTREAM DIFFUSION

B. Chezleprêtre

2. OBJECT OF THE STUDIES

The work undertaken by the Société Bertin under Contract 27/67[+] bears on the study of performances of ducted fans with downstream diffusion intended for economical support and propulsion of VTOL aircraft as well as for equipment of supporting platforms (radar mounting, anti-submarine warfare system, etc...). /5*

Contract 27/67 was written to advance studies undertaken by the Société Bertin in collaboration with Nord-Aviation several years earlier, relative to perfecting short diffusion behind a ducted fan with a high degree of efficiency.

Earlier research showed the interest in diffusion with boundary-layer control by a blast jet; as yet the work has been insufficient to permit defining a preliminary project with a blast rotor adapted to a given mission. The definition of rotors of the Nord 500 aircraft, in its first phase (weak diffusion) was established from the previously-obtained results. Research under Contract 27/67 will help Nord-Aviation to define the Phase II rotors corresponding to considerable diffusion and strong motorization.

A detailed description of the objectives of the research and the elements acquired before its start is presented in §4.

[+] Note: This report does not take into account research corresponding to 229/68 in Contract 27/67. It will be completed later.

* Numbers in the margin indicate pagination in the foreign text.

3. CHRONOLOGY OF THE OPERATIONS

CONTRACT 27/67
Notification date: 6/23/67

ORDER NO.	1	2	3	4	5	6	7
Notification date	8/24/67	8/24/67	8/24/67	11/16/67	12/7/67	5/2/68	5/30/68
OBJECT	Work Undertaken Before Contract Notification	4th Test Series at the Cannes Wind Tunnel	Fixed-Point Tests on ϕ 700 mm Models	Theoretical Studies	Experimental Studies of the Propeller	Experimental Study of an Aerodynamic Gland at Blade Tip	Various Studies and Synthesis of the Work
CHRONOLOGY	3/67-6/67 ----- Preparations for Work Described by Contract	7/67-1/68 ----- Preparation for Field Work Modification of Model 1/23/68-2/6/68 ----- Tests	7/67-10/67 ----- Preparation for Field Work, Adaptation of Model 11/67-12/67 ----- Tests	11/67-12/67 ----- Fixed-Point Two-Dimensional Diffusion 1/68 ----- Dispatch Note SIDEN RE 102	10/67-2/68 ----- Definition and Manufacture of Blades 1/68 and 3/68 ----- Tests	10/67-1/68 ----- Study and Manufacture of Blade Modifications 1/68-2/68 ----- Assembly and Tests	1/68-7/68 ----- Various Studies 6/68 ----- Dispatch NT 688c8 (Optimization of Performance Gains Through Blowing

/5A

3. CHRONOLOGY OF THE OPERATIONS (cont.)

ORDER NO.	1	2	3	4	5	6	7
		2/68-6/68 ----- Analysis and Practical Application 6/68 ------ Dispatch NT Bc7	2/68-7/68 ----- Analysis and Practical Application 7/68 ----- Dispatch NT Bc5	2/68-6/68 ----- -Nonsymmetric Shroud -Three-dimensional Diffusion 7/68 ----- Dispatch Notes Siden RE 103 and 104	4/68-6/68 ----- Analysis and Practical Application 7/68 ----- Dispatch NT 68Bc6	3/68-7/68 ----- Analysis and Practical Application 9/68 ----- Dispatch NT 68Bc9	10/68 ----- Dispatch NT 68Bc10 (Internal Operation and Free Diffusion) 10/68 ----- Dispatch NT 68Bc11 (Critical Study of Performances) 7/68-10/68 ----- Digest Report

4. OBJECTIVES OF THE RESEARCH AND ELEMENTS ACQUIRED PRIOR TO ITS START

4.1. Work before 1962

Studies carried out by the Société Bertin before 1962 per- /6
mitted approximately defining an interesting base system for a ducted rotor.

After small-scale tests, using two-dimensional models and circular models with one or several slots (with suction or blowing), the solution kept involves a shroud defined by a rheoelectric cell capable of ensuring acceleration of the boundary layers as far downstream as possible up to a single blowing slot. The diffuser is short and wide open.

Tests on a small model (ø throat = 285 mm) yielded promising results.

4.2. Contract 82/64

Research carried under Contract 82/64 (1962-1967) went in several directions simultaneously:

- --experimentation on small- and normal-scale models;
- --improvement of shroud shapes via rheoelectric analogy;
- --initial development of a mathematical model;
- --analysis of internal operation;
- --establishment of a catalogue of various theories of /7
  boundary layer control.

The main result of this contract is obtaining, with a fixed-point system, a very interesting performance using a model of normal size (ø throat = 700 mm).

The value number M'_i = 1.17 was used with the "fixed-point" type model (ϵ = 700) in a stable configuration, the corresponding blowing rate being relatively great: ϵs = 24%.

On the other hand, tests brought to light the necessity for:

--homogeneous diffuser blowing without an oblique component (a technique capable of ensuring good distribution of blowing was devised);

--the surface of the collector, the arms and the hub to be in excellent condition;

and the interest (on the normal scale) to place the blowing slot approximately 15° from the profile (angle of the tangent to the meridian of the diffuser and the rotor axis). Prior to this time, the diffuser had to be located 30° from the profile.

4.3. Objectives of Contract 27/67

The goal of Contract 27/67 is to pursue a course for perfecting short diffusion behind a ducted fan. Earlier findings have been used to define rotors of the Nord 500 aircraft in its Phase I (weak diffusion). Research under Contract 27/67 should help Nord-Aviation to approach Phase II, corresponding to rotors with significant diffusion and strong motorization. /8

The lines of action chosen are, on the one hand, general studies undertaken with the following goals:

--progressively obtaining a complete mathematical model of the flow by operating through increasing complexity;

--seeking solutions to the problem of feeding the blowing slots on the flight vehicle;

--increasing knowledge of operation inside the shroud and free diffusion.

On the other hand, the experimental studies are designed to:

--optimize the configuration developed in earlier research;

--determine the influence of the propeller parameters;

--study the possibility of using an aerodynamic gland at the blade tip.

5. DEVELOPMENT OF THE STUDY

The study was broken down into seven parts, each corresponding to an order: /9

--Order No. 1, work undertaken before contract notification;

--Order No. 2, fourth Test Series at the Cannes wind tunnel;

--Order No. 3, fixed-point tests on a ϕ = 700 mm model;

--Order No. 4, theoretical studies;

--Order No. 5, experimental fixed-point study of the propeller parameters;

--Order No. 6, experimental study of an aerodynamic gland at the blade tip;

--Order No. 7, various studies and synthesis of the work carried out under contract.

The development of the study will be described order by order; then in Chapter 6 we will present a synthesis of the results obtained.

5.1. Order No. 1. Work Undertaken Before Contract Notification

Order No. 1 corresponds to work carried out between the expiration date of Contract 82/64 and the notification date of Contract 27/67.

This research generally involves the preparation of work planned within the full extent of the contract, especially:

--preparation of the test series in the Cannes wind tunnel (Order No. 2): preliminary study of modifications of the model and establishment of the test program; /10

--preparation of a fixed-point test series (Order No. 3): study of the modifications of the model, design of new components and of the modified system;

--preliminary study of boundary-layer problems and the internal operation of the ducted fan.

5.2. Order No. 2. Fourth Test Series at the Cannes Wind Tunnel (NT 68-Bc-7)

5.2.1. GOAL

Experimentation on a simplified, nonmotorized model was conducted in the course of the 4th test series at the Cannes wind tunnel (three series were completed earlier under Contract 82/64).

The model used had an annular airfoil with tangential blowing (throat diameter = 285 mm) which could be equipped with a hub possessing sheathed base (Plate II).

This test series was undertaken, on the one hand, to develop experimentation in the presence of a hub and, on the other hand, to evaluate the influence of the position of the shroud slot on the quality of operation with and without a hub.

The model was modified in order to be able to use a diffuser /11 blowing slot closer to the throat (slot 15° from the profile instead of 30° [plate II]).

5.2.2. RESULTS

The main interest of this test series was that it demonstrated considerable improvement attained with the new position of the shroud blowing slot (slot located 15° from the profile instead of 30°).

This confirms the results observed on a larger scale with a motorized model ($\phi \simeq$ 700 mm).

The primary improvements are the following:

--progressive nature of the diffuser rejoining process. This progressiveness ensures continuous development of performances (geometric diffusion, value number), indispensable for all applications to a flight vehicle;

--quality of operation in the presence of a hub. The presence of a hub leads to a decrease of the value number from 3.5 to 7.5% for the diffusers tested at 45°, while when the slot is 30° from the profile, the decrease of M'_1 is from 19 to 32%;

--lower sensitivity to the nature of the boundary layer. When the slot is 15° from the profile, artificial triggering of the transition does not provoke the appearance of discontinuity in the performances, and the decrease of the value number remains small (5%). /12

The best performance obtained in the presence of a hub is M'_1 = 1.22 under the following conditions:

--blowing rate: Cs = 25%;

--imaginary propeller efficiency: η_p = 0.80;

--half-angle of the diffuser exit: 45°,

--nonoptimized exit section: S_3/S_1 = 1.60.

For blowing which is clearly weaker (Cs = 16%), the value number decreases slightly (M'_1 = 1.19).

5.3. Order No. 3. Fixed-Point Tests on a ϕ = 700 mm Model (NT 68-Bc-5)

5.3.1. GOAL OF THE TESTS

The tests conducted earlier (Contract 82/64) at the fixed-point test stand in Chalais-Meudon on normal-scale models (ϕ throat = 700 mm) made it possible to define a very interesting configuration, in terms of performance as well as of stability (NT 6.62), although the blowing rate was relatively great.

This configuration is characterized principally by:

--a type CD 20 B collector;

--a diffuser blowing slit located 15° from the profile (angle of the tangent to the profile with the axis of the model); /13

--a propeller placed just upstream of the shroud slot.

The goal of the test series undertaken under Contract 27/67 on the "wind tunnel" type model (ϕ throat = 682 mm; see photo, p. 36) is, on the one hand, to optimize:

--the geometry of the diffuser (Plate IV);

--the adjustment and mode of operation of the propeller;

using the configuration defined above. On the other hand, the goal is to study the influence of some parameters, including:

--the profile of the hub (Plate V);

--artificial triggering of the transition on the collector;

for the optimized configuration.

5.3.2. RESULTS

Returning to tests on the ducted fan model with "wind tunnel" type diffusion has permitted immediately confirming the quality of operation in the configuration defined above for the "fixed-point" type model (blowing slit 15° from the profile).

Moreover, comparative study of various diffusers has led to certain comments:

--the maximum value numbers obtained with all the diffusers are close to $1.16 \leq M'_{1max} \leq 1.21$; /14

--it is preferable to choose exit half-angles of 45° rather than 40°;

--the thin slot (e = 2.7 mm) permits obtaining the same value number as a wide slot (e = 4.4 mm), but with a weaker blowing rate (Plate XVII);

--there is a section relative to optimal exit (Plate XX) which, for diffusers δ_3 = 45° - e = 2.7 mm, is close to 1.68 (likewise for a diffuser with an evolutional profile). The optimal blowing rate is approximately 20%;

--the evolutional-profile diffuser tested yields results very close to those obtained with straight profiles;

--the best diffuser must be very close to the 45° diffuser with rapid recompression (Plate IV).

The definitive configuration, chosen as a result of these tests, is presented in Plate III.

Insofar as the propeller parameters are concerned, it is interesting to examine high-performance operation ($n_{II} \geq 48$ t/sec; $R_p \geq 163{,}000$) and to chose an adjustment very close to the nominal adaptation adjustment ($\theta = 37°$). A more systematic study of the propeller parameters was the object of Order No. 5. /15

Finally, the shape of the hub, with the same master frame, has little influence on the performances: $\frac{M'_{1max}}{M'_{1max}} \leq 3$, the initial hub for the model being the best (Plate XXIII).

Insofar as the position of the transition point of the collector is concerned, tests have shown that an advance of the transition point is translated into a relatively great loss of performance: $\frac{M'_{1max}}{M'_{1max}} = -8\%$ for the most advanced position; see Plate XIX).

In conclusion, the best performance obtained in the optimized configuration $M'_1 = 1.20$ for Cs = 16% corresponds to:

- --downstream lip "optimized" at 45°
- --e = 2.7 mm;
- --S_3/S_1 = 1.68;
- --operation = 49 t/sec;
- --adjustment = 37° (P/D = 1.648);
- --σ_g = 2.39.

A photo of the flow visualized through the presence of oil in the blown air is presented on page 36.

5.4. Order No. 4. Theoretical Studies
(Notes SIDEN RE 102, 103, 104)

The studies undertaken involve downstream flow of a symmetric or asymmetric shroud.

5.4.1.-A first study (RE 102) using an analogical method has /16 permitted establishing nomographs for streamlines (symmetric shroud) in a plane, irrotational, fixed-point flow.

These nomographs represent geometric diffusion which may be obtained in an ideal fluid as a function of diffuser aperture and length (Plate VII).

5.4.2.-The possibility of extending the determination of these streamlines to cases of axisymmetric three-dimensional flows (rotational shroud) was then approached (RE 104).

Different methods of calculation may be considered:

- --rheoelectric cell with successive approximations to obtain the shape of the streamline, only in the case of irrotational flow;
- --a resistant network with successive approximations which may be carried out by a hybrid computer (small computer coupled with a resistant network; a 1,000-channel computer capable of solving such a problem should be in operation at the end of 1968 at the CNRS);
- --use of triangular mesh with fully numerical resolution by a computer sufficiently powerful to absorb the approximation calculations.

The first two methods are fairly difficult to use and require, in the case of a change in configuration, as much work as for the first configuration; on the other hand, after elaboration and fairly involved adjustment, the numerical method permits treating the numerous calculation cases rapidly and economically, optimizing the configurations, etc. /17

5.4.3.-Downstream flow of an asymmetric shroud was the object of a preliminary study. A direction of research was established:

--Stage 1 - study of plane flow with semi-infinite rectilinear profiles (the method is presented in dispatch SIDEN RE 103);

--Stage 2 - study of plane flow with finite, rectilinear or nonrectilinear profiles;

--Stage 3 - study of linearized three-dimensional flow.

In the present state of affairs, practical applications of the first step and a report on the study relative to the second are possible.

5.5. Order No. 5. Fixed-Point Experimental Studies of the Propeller Parameters (NT 68-Bc-6)

5.5.1. *GOAL OF THE STUDY*

The principal parameters of the shroud of a ducted fan with downstream diffusion were optimized experimentally at the Chalais-Meudon test stand in several stages:

--NT 6/51 and 6/62 - models with throat diameters equal to 700 mm (Contact 82/64);

--NT 68-Bc-5 - model with throat diameter equal to 682 mm (Contract 27/67, Order No. 3). /18

Optimization was obtained by using a single propeller defined in NT 6/48.

Certain propeller parameters were not tested; therefore, a test series proved to be necessary. New blades were designed and manufactured with the goal of determining:

--the influence of the Cz adaptation ($0.45 \leq Cz_{adap} \leq 0.9$);

--the influence of the peripheral Reynolds number ($100{,}000 \leq R_p \leq 250{,}000$);

--the influence of the number of blades (4 and 8 blades).

In general, the measurements were made by probing: internal probing in the neighborhood of the throat and directional probing in the exit plane (see photo, p. 37)

5.5.2. *RESULTS*

The experimental fixed-point study of the propeller parameters made it possib'e to draw certain conclusions which must be carefully considered; indeed, the reduced number of configurations tested did not permit separately determining the influence of various propeller parameters. The conclusions include the following:

--the four propellers tested yielded very close value numbers: $1.15 \leq M'_{1max} \leq 1.20$; /19

--no instability was observed, even with weak blowing, in either case (4-blade propellers and 8-blade propellers);

--the optimal coefficient of blowing, on the order of ?0%, tends to increase with the Cz of operation;

--optimal geometric diffusion from the standpoint of performance is close to 2.4, whatever the mode of operation and the adjustment may be;

--the favorable effect of an increase in the peripheral Reynolds number, very sensitive up to R_p = 200,000, is maintained up to a value slightly greater than 270,000 (Plate IX);

--for a given charge at the disk, the number of blades must be chosen as a function of mechanical and technological requirements, but also in such a way that the blades operate at a periphe l Reynolds number greater than 200,000, as well as at a Cz close to the Cz of the maximum lift-drag rat. (Plate VIII).

Practical application of probing in the neighborhood of the throat and in the diffuser exit plane are part of the investigations under Orde No. 7 (NT 6(-Bc-10).

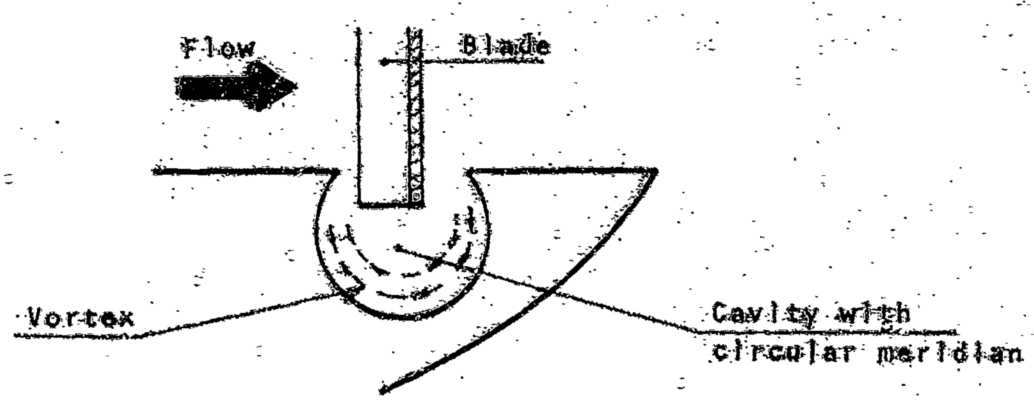
5.6. Order No. 6. Experimental Study of an Aerodynamic Gland at the Blade Tip (NT 68-Bc-9)

5.6.1. GOAL OF THE STUDY

The study of an aerodynamic gland at the blade tip, based on the vortex theory, was undertaken in collaboration with Nord-Aviation. /20

The goal sought in this study was to make progress with the difficult realization of small degrees of play at the blade tip by using a torical vortex there to serve as an aerodynamic gland. In addition, there are plans to later obtain a certain degree of diffusion in the absence of blowing as a result of the energy provided by the vortex to the boundary layers.

The experimental device used is presented schematically below:



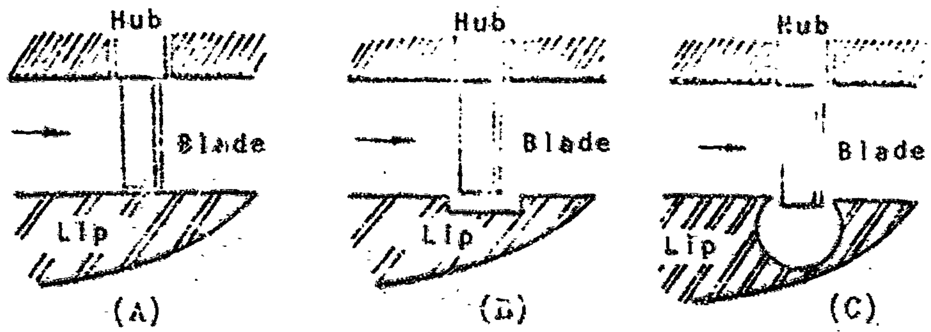
The tests were conducted at the "fixed-point" test stand of the Aerotechnical Institute of Saint-Cyr, using a ducted-fan model 400 mm in diameter lent by Nord-Aviation.

The model could be equipped with three rotational exits (for a description of the model, see Plate X):

--a reference exit (A);

--an exit with a straight meridian cavity (B);

--an exit with a circular meridian cavity (C).



5.6.2. *RESULTS*

The reference exit yielded the best results from the standpoint of total efficiency; on the other hand, insofar as aerodynamic operation is concerned, the circular meridian cavity exit offers a certain interest. We have observed the following facts in particular: /21

--improvement of the downstream flow of the propeller, in the neighborhood of the wall of the shroud, when the blades penetrate the cavity sufficiently;

--the existence of a vortex which is approximately centered on the axis of the cavity with zero velocity at the center;

--the meridian barriers are indispensable in the cavity to obtain a certain level of efficiency; they prevent rotation of the vortex with the propeller.

The favorable elements permit hoping to arrive at a satisfactory solution for an aerodynamic gland favoring diffusion. For this, a systematic study of the various parameters will have to be made. /22

The findings in the course of this first experimental study can be compared with those presented by Haugen and Dhanak relative to the flow, which appear to be separate when one pipe involves a cavity.

In the case of a cavity with a square meridian, Haugen and Dhanak established the existence of a vortex on the axis of the cavity with zero velocity at the center by visualization (see photo, p. 37) and mathematically.

5.7. Order No. 7. Various Studies and Synthesis of the Work Carried Out Under Contract (NT 68-Bc-8, 68-Bc-11, 68-Bc-10, 69-Bc-17)

The performances considered to this point, as far as ducted fans with blowing are concerned, are calculated without taking into account the efficiency of the generation of compressed air for blowing and without considering how this blowing can be realized on a flight vehicle.

A parametric study was conducted (NT 68-Bc-8) to further knowledge in this area; it was followed by numerical application to the case of the Nord 500 aircraft.

Parallelly, a critical analysis of performances obtained with a ϕ = 682 mm model (NT 68-Bc-11) was made with two purposes in 723
mind: (a) to confirm the base performances taken in the parametric study cited above; and (b) to permit a valid comparison of the essentially different results obtained by Nord-Aviation using a model 400 mm in diameter.

Moreover, due to the body of experimental data obtained with the optimized configuration of the ϕ = 682 mm model (summary measurements, probing, etc.), knowledge of internal operation and free diffusion was advanced. The findings are presented in NT 68-Bc-10.

Finally, synthesis of all the work done under contract is the object of this document (NT 68-Bc-17).

5.7.1. PARAMETRIC STUDY AND OPTIMIZATION OF THE GAIN IN PERFORMANCE AT CONSTANT POWER AFFORDED BY AN ON-BOARD BLOWING DEVICE (NT 68-Bc-8)

In order to be able to optimize the gain in thrust provided by blowing in the case of a ducted fan with the same motorization, a parametric study of blowing was conducted for the fixed-point case.

The generation of blowing is assumed to be ensured by a turbomachine (air blower or compressor), the necessary power being supplied by the motor driving the propeller. Two solutions are envisaged:

--direct use of the generator output; /24

--use of a compressor in conjunction with pump-effect dilution, permitting the reduction of the necessary output.

Note 68-Bc-8 presents equations for this, including the representation of equations in nomographs as well as numerical applications based on the performances obtained with the ϕ = 682 mm model in its optimized configuration and with the results obtained using multitube pumps. Moreover, the Nord 500 aircraft has served as a reference for the installation of an on-board blowing system to demonstrate the blowing performances obtainable by considering the difference between an increase in rotor thrust and the corresponding increase in the mass of the aircraft.

In the study it was found that, on the level of rough gain in thrust, the direct use of the output of an air blower feeding the two rotors offers the best solution, but that in contrast, the necessary sections of piping make its installation on the aircraft very difficult. The study of optimization has therefore been limited to the case of a compressor in conjunction with a dilution system.

Plate XI shows the installation of the system on the Nord 500 aircraft, and Plate XII shows the dilution system in detail.

The system was optimized on the basis of the following hypotheses:

--compressor efficiency: 0.85; /25

--compressor motor transmission efficiency: 0.98;

--pump efficiency: 0.46;

--coefficient of loss of charge in piping: 2.

The optimum obtained corresponds to:

--blowing rate: Cs = 8% (value corresponding to the lower limit of admissible operation);

--excess pressure ratio: $\pi = 1.5$;

--rate of dilution: $x = 4.35$;

--piping machinery: $M = 0.1$;

--gain in payload: 185 daN (22% of the weight of the unloaded Nord 500, 16% of the total weight).

5.7.2. CRITICAL STUDY OF PERFORMANCES (NT 68-Bc-11)

A critical study of the performances using the ϕ = 682 mm model in its practically optimized configuration was undertaken; after critical examination of the measurement methods and general development of calculations of errors, the possible inaccuracy of the best test points was calculated.

The probable error for an isolated point is:

$$\frac{\Delta M'_1}{M'_1} = \pm 4.75\%,$$

and the value of the best performance is written: /26

$$\boxed{1.17 \leq M'_{1max} \leq 1.28}$$

In fact, the possible error is reduced by smoothing the results obtained for numerous test points.

5.7.3. ANALYSIS OF INTERNAL OPERATION AND FREE FIXED-POINT DIFFUSION FROM EXPERIMENTAL FINDINGS (NT 68-Bc-17)

Object: Internal operation and free diffusion (diffusion in the absence of material walls downstream of the diffuser) were analyzed using the optimized configuration of the ϕ = 682 mm model; this was made possible by the body of experimental values collected (summary measurements and probing).

The internal operation is determined by following the evolution of the flow between the throat and the exit plane of the model, taking into account the air introduced into the shroud and hub blowing slots.

Free diffusion is calculated from the conditions of flow in the exit plane of the model.

Moreover, integration of the values obtained *via* probing may be compared with the summary measurements.

Results: the results presented in Note 68-Bc-10 seem to be valid; nevertheless, it is necessary to consider them carefully due to the inaccuracy of the measurements and calculations. /27

The results bear primarily on the following points:

--velocity profiles (in the neighborhood of the throat, in the exit plane and infinitely downstream);

--outputs (distribution and intersection);

--thrust (intersection in the exit plane and infinitely downstream and summary measurements);

--internal energy balance (distribution of power and losses, behavior of the blast jets, propeller efficiency, etc.);

--geometric diffusion (intersection);

--rotation of inflow (angle of twisting in the exit plane and infinitely downstream; power lost in the case of twisting).

It would seem that the blowing power would be used in approximately the following way:

--residual power of the blast jets: 9%;

--power received by the primary inflow: 23%;

--losses (transfer and friction): 68%.

On the other hand, the output continuity and the calculation of free diffusion has made it possible to trace the current lines separating the zones of equal output (Plate XIII).

5.7.4. DIGEST REPORT (NT 68-Bo-17)

The synthesis of the work and results obtained is the object of this report. /28

6. RECAPITULATION OF THE RESULTS

The experimental studies constituted the largest part of the research program, and the findings are numerous. The main results are: completing the improvements on normal-scale models ($\phi \simeq 700$ mm) in the fixed-point case, and obtaining stable, high-performance operation of blowing under these conditions.

An examination of performance and the influence of the parameters is presented in §6.1. Various studies, an analysis of internal operation and free diffusion, the realization of blowing on a flight vehicle and of an aerodynamic gland at the blade tip will be the object of §6.2. Finally, the state of progress in theoretical studies is described in §6.3.

6.1. Performances--Influence of the Parameters

Experimental studies relative to Contract 27/67 were conducted in parallel with the motorized "wind-tunnel" type model (ϕ = 582 mm) at the fixed-point test stand in Chalais-Meudon and with the nonmotorized model (ϕ = 285 mm) at the Cannes wind tunnel.†

The results presented in this synthesis are mainly those obtained with an advanced blowing slot, i.e. a slot 15° from the profile instead of 30° as before, since these results are essentially greater than those found earlier (§6.1.2.1).

6.1.1. TOTAL PERFORMANCES

The maximum value numbers obtained in the fixed-point case with motorized Bertin models are reviewed in the table below: /29

† Note: The nonmotorized tests (Cannes) are analyzed considering that the flow is obtained by an imaginary propeller with an efficiency of 0.88 (NT 68-Bc-7).

FIXED-POINT MOTORIZED TESTS				
Model, Site	Reference	N'_{max}	$Cs(N')_{max}$	Observations
ϕ = 285 mm la Gare Bridge	NT 6.22 April 63 Contract STAé 3015.60	1.22 1.24	20% 24%	-Plate in the Collector Entrance Place -Feeding of Shroud Blowing by 18 Radial Pipes -Good Stability
Pseudo-Fixed-Point "Wind Tunnel". ϕ = 700 mm Toulouse	NT 6.39 Tests: April 64 Contract DRME 82/64	1.26	11%	-Extrapolation from Low-Velocity Fixed-Point Tests -Abnormally Favorable Influence of an Increase in the Mode of Operation
"Wind Tunnel" ϕ = 700 mm Chalais-Meudon	NT 6.51 July 66 Contract DRME 82/64	1.16	30%	-Distribution of Blowing Completely Modified -Improved Surface Condition and Comparisons -Good Stability
"Fixed-Point" ϕ = 700 mm Chalais-Meudon	NT 6.22 April 67 Contract DRME 62/64	1.17	24%	-Blowing Slot of Shroud Advanced from 30° to 15° - Very Good Stability
"Wind Tunnel" ϕ = 682 mm Chalais-Meudon	NT 68-Bc-5 June 68 Contract DRME 27/67	1.20	16%	-Blowing Slot of Shroud at 15° - Very Good Stability

It took a long time to obtain high performance (with a weak rate of blowing and satisfactory stability) on the normal scale ($\phi \simeq$ 700 mm), but this provided a great deal of valuable information. This project was carried out at the fixed-point test stand in Chalais-Meudon. /30

We may consider the last configuration tested (Plate III) to be optimized.

In parallel with these motorized tests, experimentation in the absence of a propeller in the Cannes wind tunnel yielded the results compiled in the following table.

Model	Reference	M'_{1max} (*)	Cs(M'_{1max})	Observations
"Cannes" ϕ = 285 mm	NT 68-Bc-7 Contract DRHE 27/67	1.15	12%	Nonoptimized Exit Section (S_3/S_1 = 1.44)
		1.20	26%	Nonoptimized Exit Section (S_3/S_1 = 1.80)

* Value corresponding to an imaginary propeller efficiency of η_P = 0.88.

The evolution of the value number and geometric diffusion as a function of the blowing rate is traced in Plate XIV for ϕ = 682 mm models (Chalais-Meudon) and ϕ = 285 mm models (Cannes).

The geometric diffusion corresponding to the maximum value number in the configurations shown in Plate XIV has the value:

Model	σ_g (M'_{1max})	Observations
ϕ = 682 mm	2.39	Optimized Exit Section S_3/S_1 = 1.68
ϕ = 285 mm	2	Nonoptimized Exit Section S_3/S_1 = 1.44
ϕ = 285 mm	2.84	Optimized Exit Section S_3/S_1 = 1.8

/31

Critical analysis (NT 68-Bc-11) of the measurement methods, recordings and analyses has permitted evaluating the different errors entering the determination of the value number (systematic and random errors). The calculation made for an isolated point, chosen from among the best points determined, led to:

$$\boxed{1.17 \leq M'_{1max} \leq 1.28}$$

In fact, this uncertainty may be reduced by taking numerous results into account.

Moreover, the performances obtained by Nord-Aviation with a model 400 mm in diameter are clearly inferior; the causes of the deviations observed (apparently linked with the differences existing between the models) will be the object of research within the /32 scope of Contract 27/67.

6.1.2. BLOWING SLOT

The influence of the position, the thickness and the homogeneity of the blowing slot of the shroud is considered.

6.1.2.1. Position of the Slot

A test series using a ϕ = 700 mm model (NT 6.62, Contract 82/66) shows the interest in placing the slot 15° from the profile rather than 8° or 30° from it. This result was confirmed on the ϕ = 285 mm model at Cannes (best results were with the slot at 15°). The 15° position affects the value number (Plate XV) and on the stability of the flow. On the two models, the intersection of the diffuser with the slot at 15°, when blowing was increased, is progressive, while with the slot at 30°, intersection is abrupt, primarily in the tests without a propeller at Cannes (NT 68-Bc-7).

6.1.2.2. Thickness of the Slot

Plates XVI and XVII show the influence of the thickness of the blowing slot of the shroud on geometric diffusion and the value number, respectively. Let us note that thin slots are preferable for economical blowing operations. In contrast, for high blowing rates it is interesting to widen the blowing slot rather than to increase /33 the velocity of the jet.

The blowing rate corresponding to the maximum value number increases when the thickness of the slot increases.

On the other hand, the thickness of the slot must be adapted to the configurations (scale, surface condition, geometric diffusion, etc.); in effect, artificial triggering of the transition in the course of the 3rd test series at Cannes (Contract 82/64) demonstrated that, in contrast to what is observed in natural transition, the thickest slot was then the best.

6.1.2.3. *Distribution of Blowing at the Slot*

The quality of the distribution of azimuth blowing is important; indeed, inhomogeneous distribution, especially in the presence of oblique zones, leads to the existence of weak zones in the fluid film. This is expressed either by asymmetric separation or by the necessity to use excess blowing in the strongest regions.

A technique for feeding the slots was perfected. The distribution of blowing during the optimization tests on a ϕ = 682 mm model is presented in Plate VI. /34

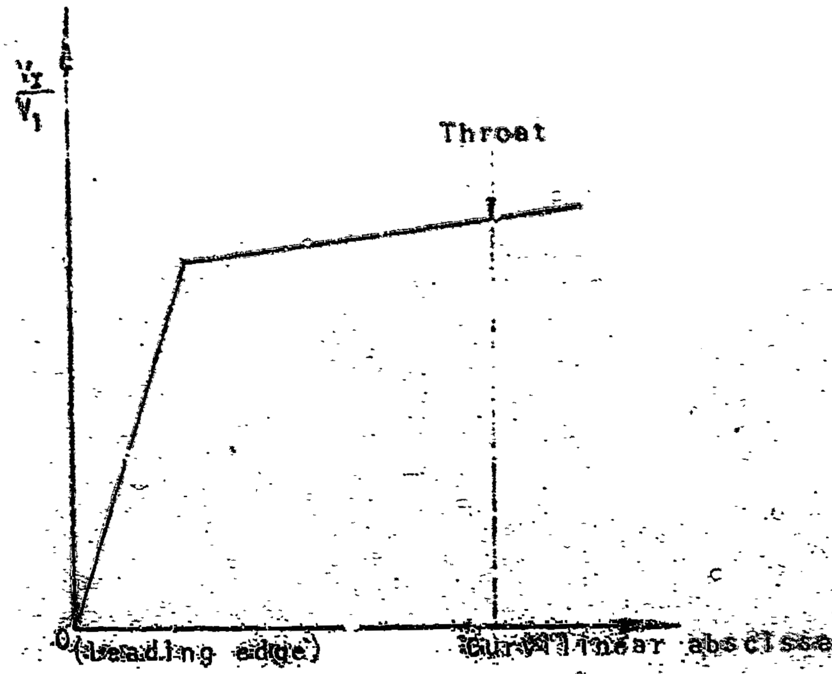
The gain obtained by improvement of the homogeneity of blowing under Contract 82/64 could not be dissociated from that due to improvement of the surface condition of the collector (total relative gain of the value number: 10%).

6.1.3. *COLLECTOR*

6.1.3.1. *Profile of the Collector*

The profile of the collector in the two models used is the same. This profile (CD20B) was obtained through an analogical study (NT 6.27, Contract 82/64). It ensures a velocity profile at the wall inside the shroud characterized by the absence of excess velocity in the neighborhood of the entrance and by the maintenance of a positive velocity gradient beyond the throat.

Profile CD20B is well adapted to the fixed-point case. Other profiles were determined (Contract 82/64) to ensure a satisfactory compromise between the fixed point, the translation and oblique incidence.



6.1.3.2. *Surface Condition of the Collector*

The surface condition of the shroud is an important parameter, especially on the scales used for the models. Reflection of the collector in the ϕ = 700 mm model (NT 6.41, 46, Contract 82/64) permitted increasing the transition Reynolds number of the shroud from 540,000 to 1,200,000. The corresponding gain in performance could not be dissociated from that due to improvement of the distribution of blowing, since the total value number relative to these two parameters was approximately 10%. /36

On the other hand, artificial triggering of the transition by bonding with carborundum grains showed that the blowing power necessary to obtain a given diffusion was greater in triggered transition than in natural transition (Plate XVIII), and that the corresponding losses in the value number were from 5 to 8% (Plate XIX).

6.1.4. DIFFUSER

In the fixed-point case, the value number is related to geometric diffusion by the relationship:

$$M'_1 = \eta'_1 \sqrt{\sigma_g},$$

where the total efficiency η'_1 includes losses due to the propeller as well as those of the collector and diffuser.

We can see that to obtain a high value number, we need considerable downstream diffusion. For example, in order to have M'_1 = 1.2, we must have diffusion σ_g such that: /37

$$1.78 \lesssim \sigma_g \lesssim 2.94 \text{ if } 0.7 \lesssim \eta'_1 \lesssim 0.9.$$

This shows that the relative exit section of the diffuser will have to be fairly high. The choice of the diffuser is ensured by experimental optimization.

6.1.4.1. Relative Exit Section S_3/S_1 (Plate XX)

The relative exit section is an important parameter, especially for configurations capable of providing high performances.

Plate XX shows the evolution of the maximum value number for diffusers with a 45° half-angle. The optimal relative exit section of the ϕ = 682 mm model is 1.68.

In the absence of a hub, the optimal section seems to be clearly higher (Cannes model).

The results obtained at Quai de la Gare (1962) on a ϕ = 285 mm model are also shown in this figure. The relative exit section being ensured, the best mode of operation in this case is 1.66 (non-optimized value).

In this plate, we can still note that geometric diffusion corresponding to the maximum value numbers increases regularly when /38 the exit section increases.

6.1.4.2. Diffuser Aperture (Plate XXI)

The best performances were realized with the model corresponding to a 45° half-angle of aperture.

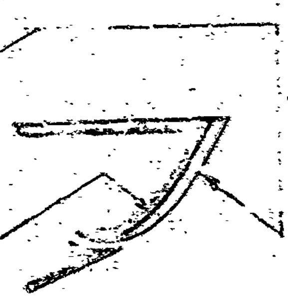
Plate XXI presents the results obtained at Cannes and Chalais-Meudon when the blowing slit is 15° from the profile.

It appeared that values less than 45° yielded lower value numbers; in contrast, larger values (50° and 60°) yield practically the same value numbers but with higher blowing rates. The choice of the 45° value therefore seems justified.

6.1.4.3. *Profile of the Diffuser (Plate IV)*

The diffuser profiles tested at Chalais-Meudon are presented in Plate IV. In particular, for 45° diffusers with a straight meridian, we obtained:

M'_{1max}	Cs (M'_{1max})
Diffuser at 45° with Slow Recompression	
1.19	22%
Diffuser at 45° with Rapid Recompression	
1.21	17.5%



The shortest diffuser (rapid recompression) yields the best result, but it seems that it must be at the limit of possibility, without the risk of making the configuration untenable in the range of blowing considered (NT 68-Bc-5, p. 60).

Moreover, a diffuser with a rotational profile has given results close to those obtained with a straight profile.

6.1.5. *HUB (PLATES XXII AND XXIII)*

Tests on the nonmotorized model (Cannes) showed that the presence of a sheathed hub introduces a loss in performance (geometric diffusion, Plate XXII; value number, Plate XXIII). This loss is greater with a long diffuser than with a short one.

On the other hand, with the motorized model the tests with different sheathed hubs of the same diameter (Plates XXII and XXIII) yielded very similar results. /40

The influence of blowing on the hub base is expressed as shown in the following table (Cannes model).

K'_{1max}		Observations
Sheathed Hub	Unsheathed Hub	
1.15	1.10	S_3/S_1 = 1.44
1.31	1.02	S_3/S_1 = 1.8

6.1.6. ARMS

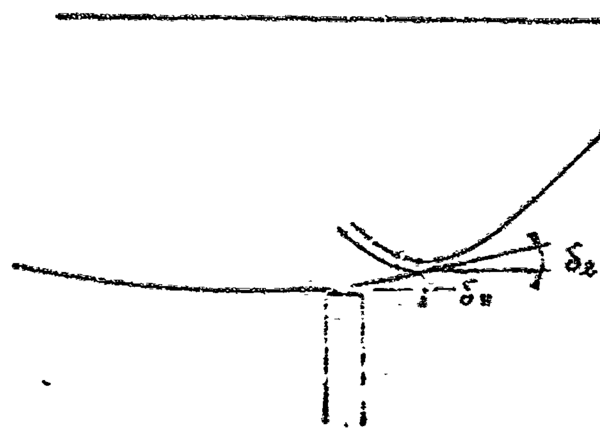
The models used have arms located approximately between the entrance plane and the throat. The presence of these arms is translated by an increase in the wetted surface and by a drop in propeller efficiency due to wake effect.

Adding 6 arms to the 3 existing arms in the ɸ = 700 mm model lowered the value number by 9% (NT 6/59, Contract 82/64).

6.1.7. PROPELLER

6.1.7.1. Plane of the Propeller (NT 6.62)

The influence of the plane of the propeller on the shroud is poorly dissociated from the influence of slot position, since not enough configurations have been tested. We can say only that the best results were obtained with the propeller and slot 15° from the profile, the propeller being just upstream of the slot. /41



Propeller Position $\delta H°$	Slot Position $\delta_2°$	M'_{1max}	Observations
30	30	1.06	
15	15	1.175	NT 6/62
8	15	1.105	
8	8	1.085	Contract 82/64

6.1.7.2. *Adjustment*

The performances depend on the adjustment of the propeller, and it appeared that the optimal adjustment for the system is fairly close to that predicted by theory.

For example, a variation in adjustment of 10° may lead to a variation in the value number of approximately 10% (NT 68-Bc-5 and 66-Bc-6).

6.1.7.3. *Peripheral Reynolds Number (Plate IX)*

When the Reynolds number increases, a favorable effect on the value number is observed. This effect is apparent up to R_p = 160,000 (Propeller 0, NT 68-Bc-5) or up to R_p = 270,000 (Propellers 1-4, NT 63-Bc-6, Plate IX).

6.1.7.4. *Propeller Type*

The propellers tested were calculated at constant circulation, using either the Toussaint method or a fairly similar one. The existence of a nonuniform velocity field in the plane of the propeller was taken into account.

6.2. Various Studies

6.2.1. *INTERNAL OPERATION AND DOWNSTREAM FLOW (NT 68-Bo-10 AND 5.7.3)*

The internal operation corresponding to the optimized configuration was the object of a detailed analysis made possible by probing and the body of measurements taken. The conditions infinitely /63 downstream were then determined by calculating from the conditions in the diffuser exit plane (free diffusion phase).

It would seem that the blowing power would be used in approximately the following way:

- --residual power of the blast jets: 9%;
- -- power received by the primary inflow: 23%;
- -- losses (transfer and friction): 68%.

Plate XXIV shows the profiles of total pressure taken in the diffuser exit plane for different models and blowing rates. It is evident that the wake of the leading edge of blowing practically disappeared.

6.2.2. *REALIZATION OF BLOWING ON A FLIGHT VEHICLE (NT 68-Bo-8 AND §5.7.1.)*

The performances considered above were calculated without taking into account the efficiency of compressed air generation.

A parametric study made it possible to optimize blowing by taking various losses into account (compresser, piping and eventually pumps).

The optimum blowing rate is in the neighborhood of the limit of stable operation ($C_s \simeq 8\%$), the value number (efficiency of generation of compressed blowing) being close to 1.02.

C.2.3. AERODYNAMIC GLAND AT BLADE TIP (NT 68-Bc-9 AND 55.6)

The experimental study of an aerodynamic gland at the blade tip *via* rotation of a vortex in a torical cavity yielded some encouraging results.

The goal sought is to come closer to realizing small degrees of play at the blade tip and to obtain a certain level of diffusion, as a result of the energy provided by the vortex to the boundary layers.

6.3. Theoretical Studies

The object of the theoretical studies is to obtain a satisfactory mathematical model. The complexity of the problems involved leads to operating in stages of increasing difficulty.

The first studies (Contract 82/65) were relative to the determination by an analogical method of the flow around a ducted fan with a fixed-point regime and with axial translation (Report BEST R 2[illegible]6), using the following simplified hypotheses:

--ideal incompressible fluid;

--propeller replaced by a pressure discontinuity disk;

--irrotational or rotational flow;

--absence of rotation of inflow.

Resolution of the problem in the most general case of rotational flow necessitates the use of a lattice (equation with a second member). In contrast, the case of irrotational flow may be treated either by a lattice or by a rheoelectric cell. /45

The first step in this investigation consisted of eliminating practical difficulties with the use of lattices by comparing the findings with the cell and with the lattice in the case of the shroud CD20B in irrotational flow (Report BEST R 308). Next, rotational flow was treated with application to the shroud CD39B (Report BEST R 317 and SIDEN RE 101).

In view of reaching a solution to the complete problem (rotational flow--unknown streamline, etc.) the studies were pursued (Contract 27/67) by seeking the streamline downstream of the diffuser.

Only the following case was treated (Report SIDEN RE 102):

--plane flow;

--fixed point;

--irrotational flow;

--ideal incompressible fluid.

In the usual case, research of methods to determine the streamline showed (Report SIDEN RE 104) the interest in using networks with triangular meshes rather than rectangular ones and an entirely numerical solution rather [illegible] an analogical or hybrid one. The investigations will be carried out in this direction.

Besides the studies mentioned above, two specific investigations were conducted:

--a project for studying diffusion by the blast jet at the trailing edge of a ducted fan in an ideal incompressible fluid in irrotational axisymmetric flow (Report SIDEN RE 200, Contract P2/64);

--research of a method for calculating asymmetric shrouds in an ideal incompressible fluid, in plane and axisymmetric irrotational flow (Report SIDEN RE 103, Contract 27/67).

7. CONCLUSIONS AND FINAL PERSPECTIVES

The research in collaboration with Nord-Aviation under Contract 27/67 made the following possible:

--fixed-point optimization of the configuration (Plate III) with data from earlier research: total performance was slightly improved and the corresponding blowing rate was essentially reduced (value number: $N'_1 \simeq 1.2$; blowing rate: $Cs \simeq 16\%$) without the appearance of any instability of operation;

--advance in knowledge of the influence of various parameters on performance;

--a more detailed analysis of internal operation, in particular the behavior of the blast jet;

--a parametric study of the installation of blowing on a flight vehicle, in particular by using compressed air at average pressure feeding a multitube pump placed near the blowing slot (numerical application to the case of the Nord 500 aircraft);

--a preliminary study of an aerodynamic gland at the blade tip; /47

--continuation of development of a mathematical model of the flow.

Exchanges with Nord-Aviation indicate that subsequent research projects ought to be oriented in the following directions:

--analysis and explanation of divergences between the results presented in this report and those found by Nord-

Aviation using a fairly similar configuration on a different scale (throat diameter - 400 mm);

--extension of the results obtained in the fixed-point case with a slight positive or negative transition, representing takeoff or landing of a VTOL aircraft;

--increase of the power at the disk and study of the influence of compressibility of the air on the performance of a strongly-motorized rotor (500 to 1000 kW/m²);

--transposition of the laboratory results to aircraft rotors;

--analysis of sonic phenomena in ducted fans and research of principles applicable to the conception of a rotor to reduce the sonic effects.

LIST OF PLATES

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PHOTOGRAPHS

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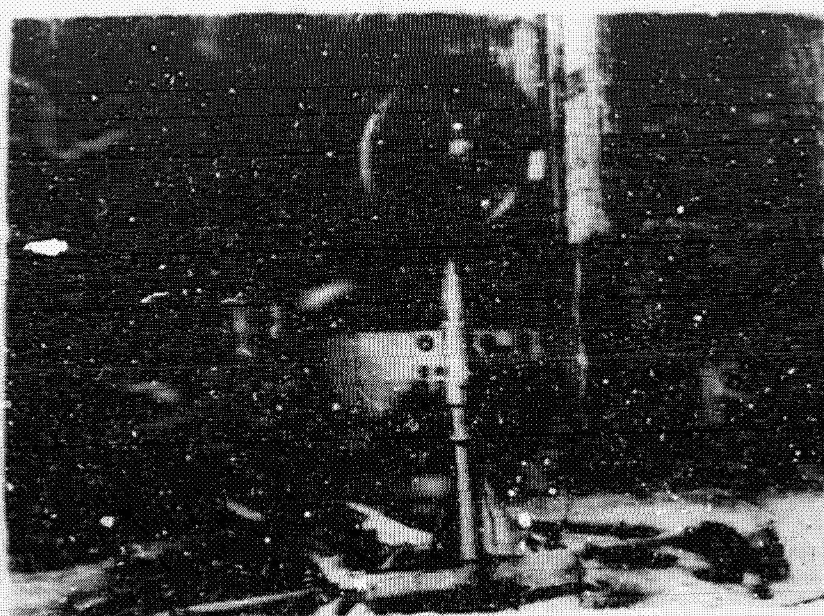
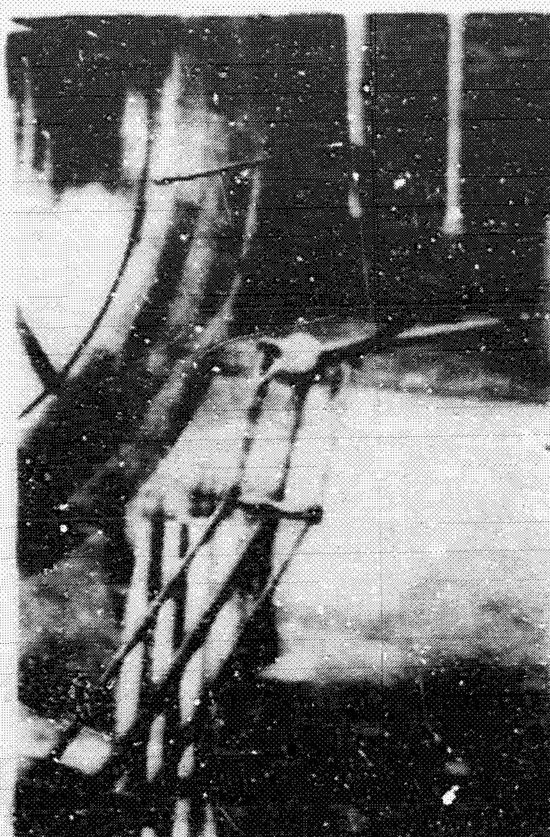


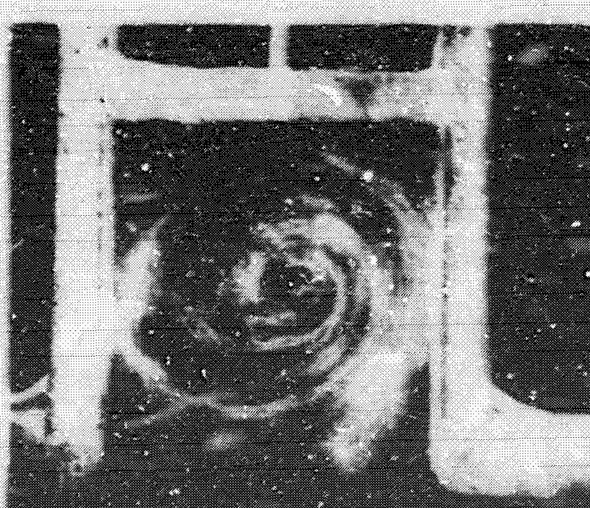
"Wind Tunnel" Type Model
(ϕ = 682 mm).

Chalais-Meudon Fixed-Point Test
Stand; Visualization of the Flow.

/50



Three-Direction Probing;
c = 682 mm Model.



(a) h/k = 1.0,

Visualization of the Vortex
in the Square Meridian Cavity
(Haugen and Dhanak).

APPENDIX

LIST OF TECHNICAL REPORTS ESTABLISHED UNDER CONTRACT 27/67

NT 68-Bc-7 – Ducted Fans with Downstream Diffusion. Fourth Test Series at the Cannes Wind Tunnel. /51
Order No. 2
D. Poncet-Montage.

NT 68-Bc-5 – Ducted Fans with Downstream Diffusion. ϕ = 682 mm "Wind Tunnel" Type Model. Experimental Optimization.
Order No. 3
J. Halet.

SIDEN RE 102 – Nomographs of Streamlines at the Diffuser Exit in Irrotational Plane Flow.
Order No. 4
R. Maria-Sube.

SIDEN RE 103 – Ducted Fans, Preliminary Study of Jet Deviation Engendered by an Asymmetric Shroud.
Order No. 4
R. Maria-Sube.

SIDEN RE 104 – Study Project of Streamlines at the Diffuser Exit.
Order No. 4
R. Maria-Sube.

NT 68-Bc-6 – Ducted Fans with Downstream Diffusion. ϕ = 682 "Wind Tunnel" Type Model Fixed-Point Propeller Tests.
Order No. 5
P. Lefevre.

NT 68-Bc-9 – Ducted Fans with Downstream Diffusion. Saint-Cyr Fixed-Point Test Stand. Experimental Study of an Aerodynamic Gland at the Blade Tip.
Order No. 6
J. Halet.

NT 68-Bc-8 – Ducted Fans with Downstream Diffusion. Parametric Study and Optimization of Gain in Performance at Constant Power Afforded by an On-Board Blowing Device. /52
Order No. 7
R. Schlegel.

NT 68-Bc-10 – Ducted Fans with Downstream Diffusion. Analysis of Internal Operation and Fixed-Point Free Diffusion from Experimental Findings.
Order No. 7
B. Chezlepretre.

NT 68-Bc-11 – Ducted Fans with Downstream Diffusion. ϕ = 682 mm "Wind Tunnel" Type Model. Critical Study of Performances.
P. Lefevre.

NT 68-Bc-17 – Ducted Fans with Downstream Diffusion. Contract DRME 27/67. Digest Report.
Order No. 7
B. Chezlepretre.

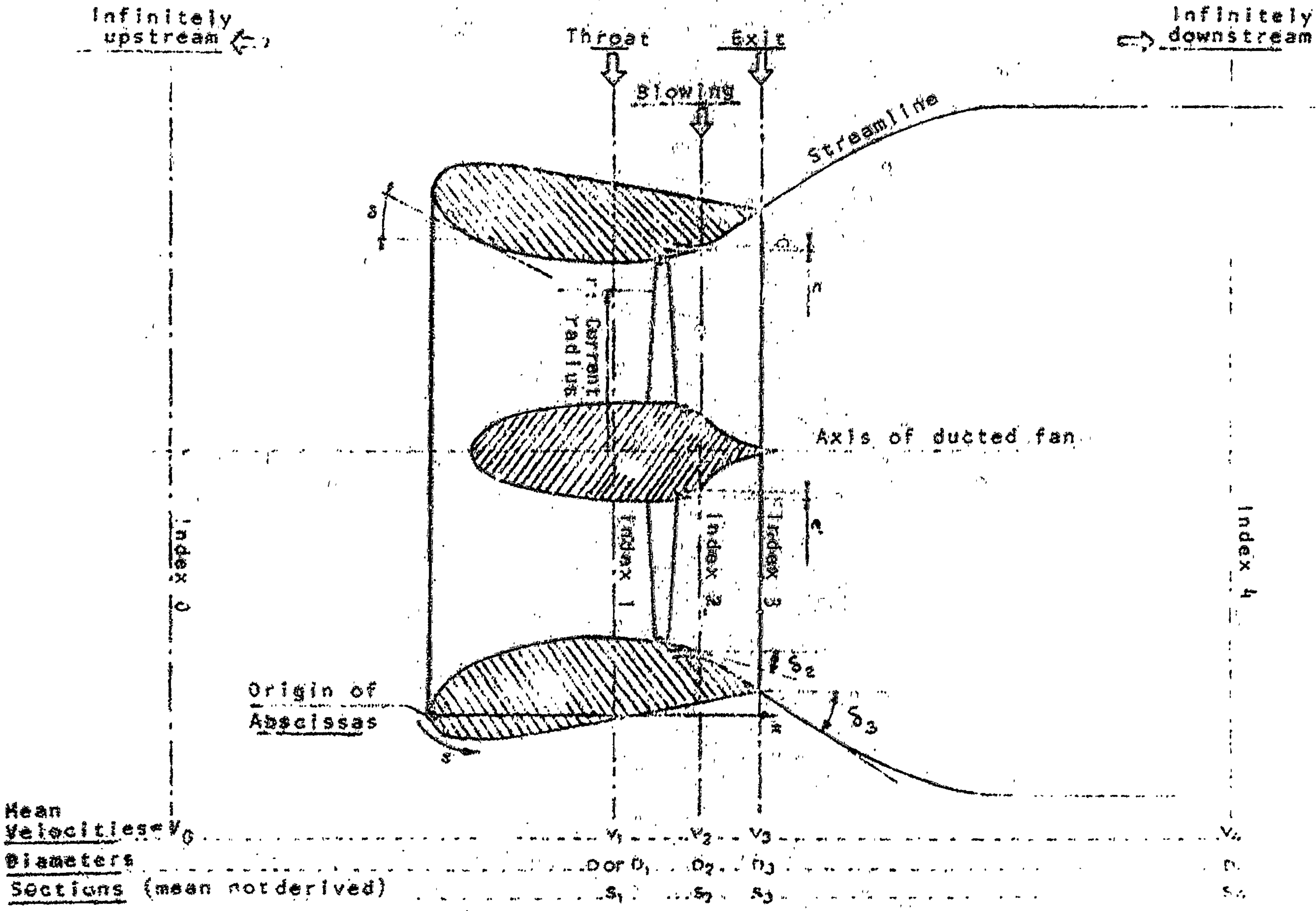


Plate I. Indices of Position: Symbols and Notations.

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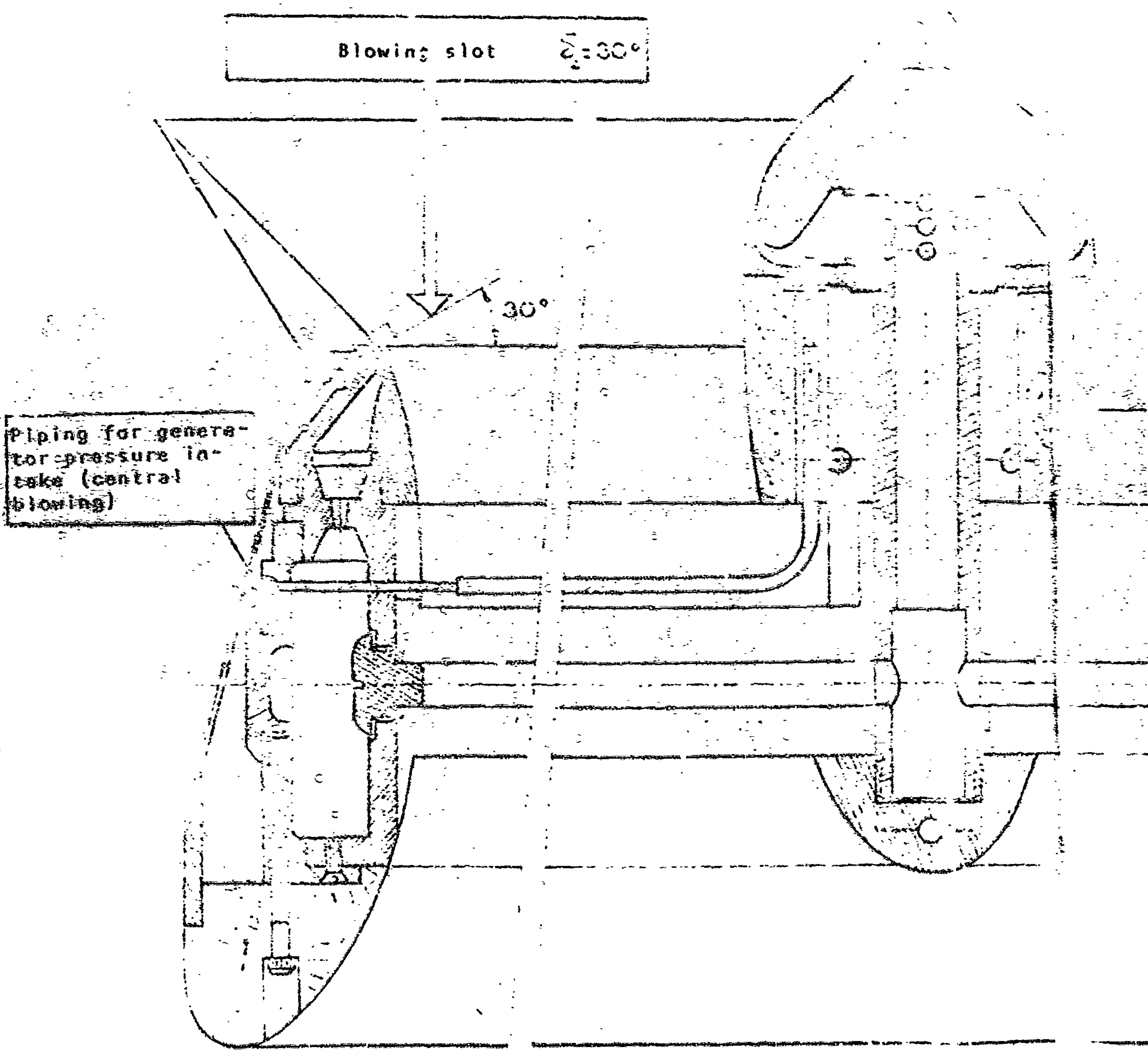

Plate II. Cann:s Model (¢ = 285 mm): Di

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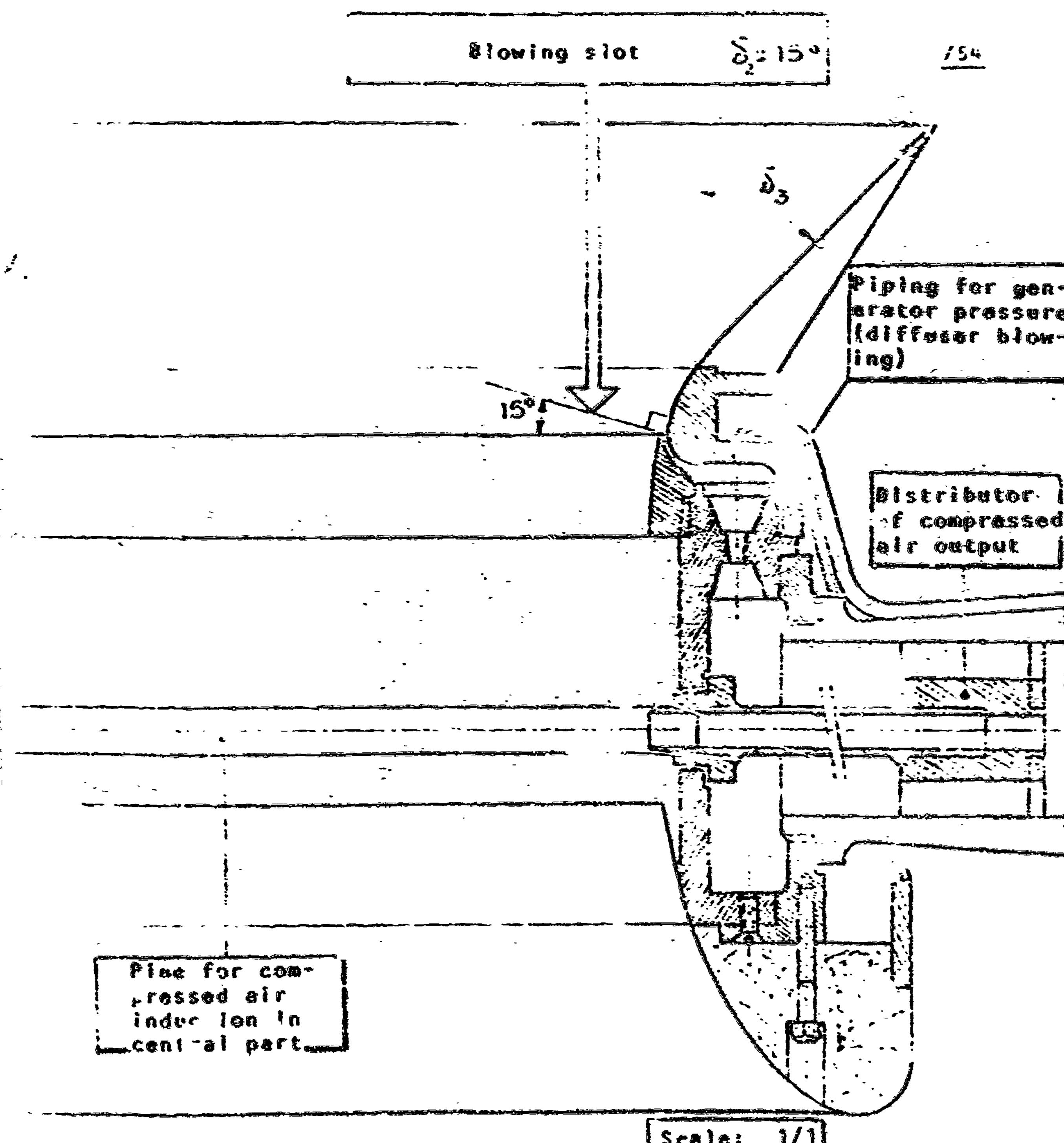

J: Diffuser and Hub Blowing

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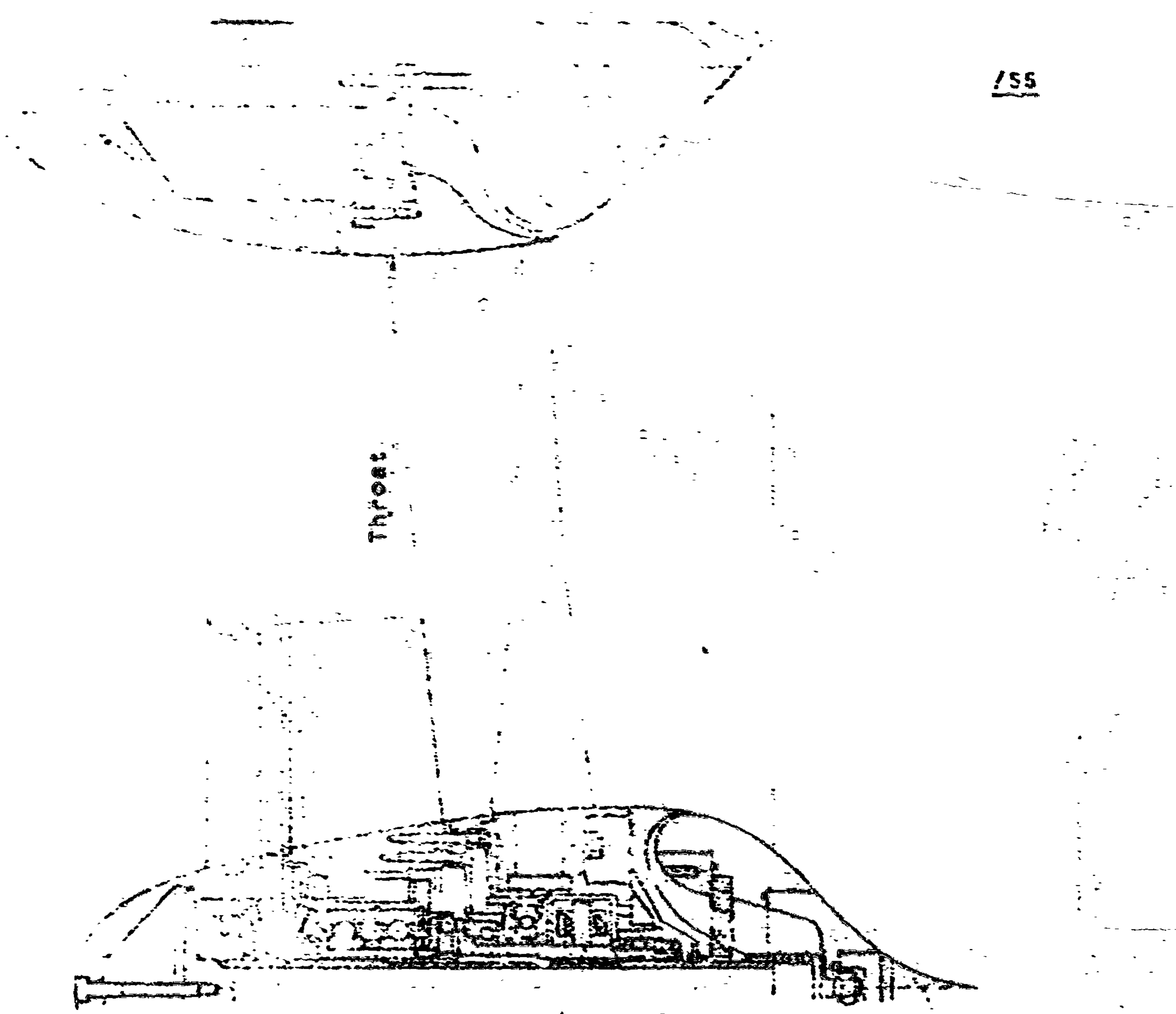
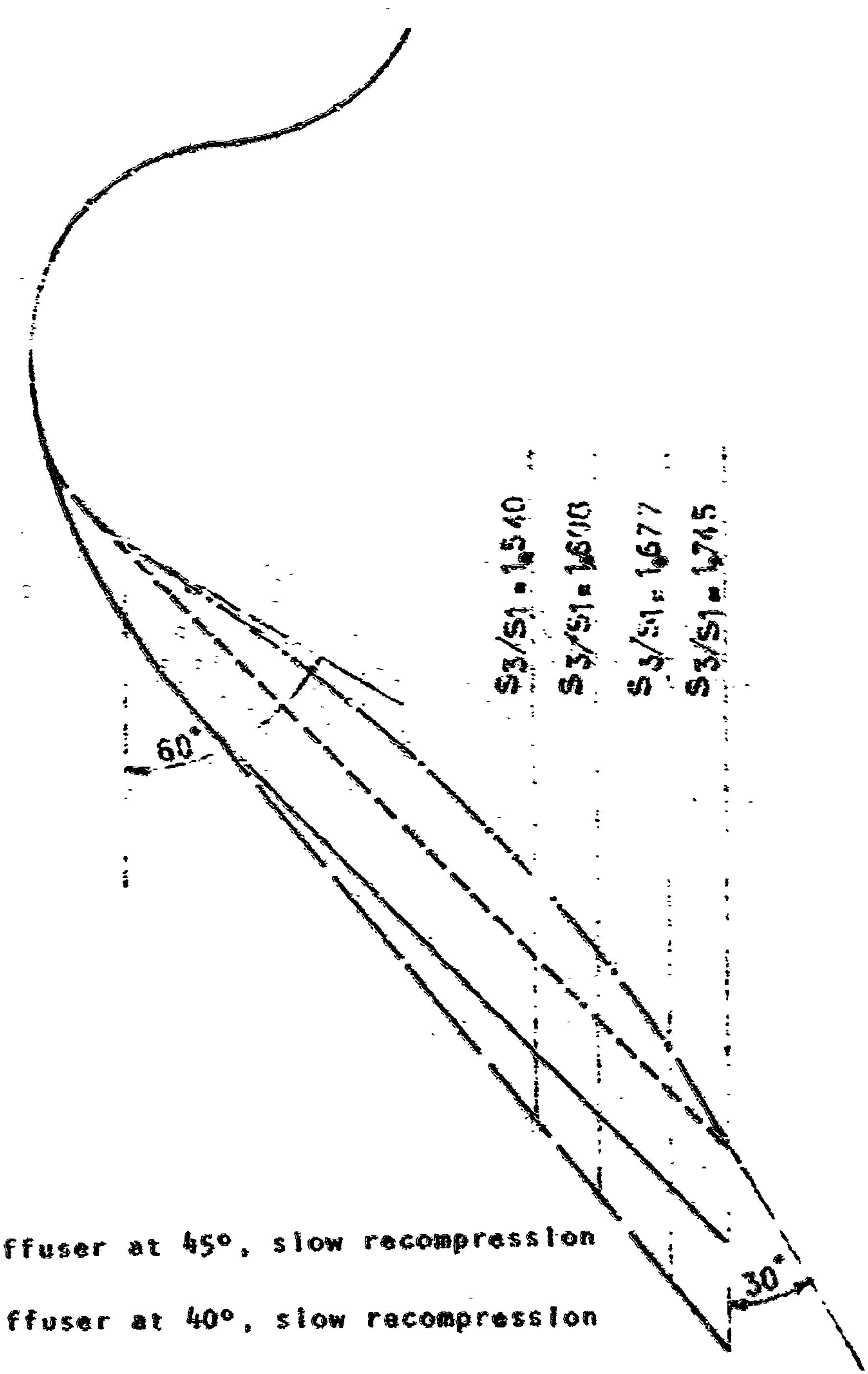


Optimized configuration

Plate III. "Wind Tunnel" Type Model (ϕ = 682 mm).



Diffuser at 45°, slow recompression

Diffuser at 40°, slow recompression

Diffuser at 45°, rapid recompression

Rotating diffuser

Plate IV. Comparison of Diffusers; ϕ = 682 mm Model.

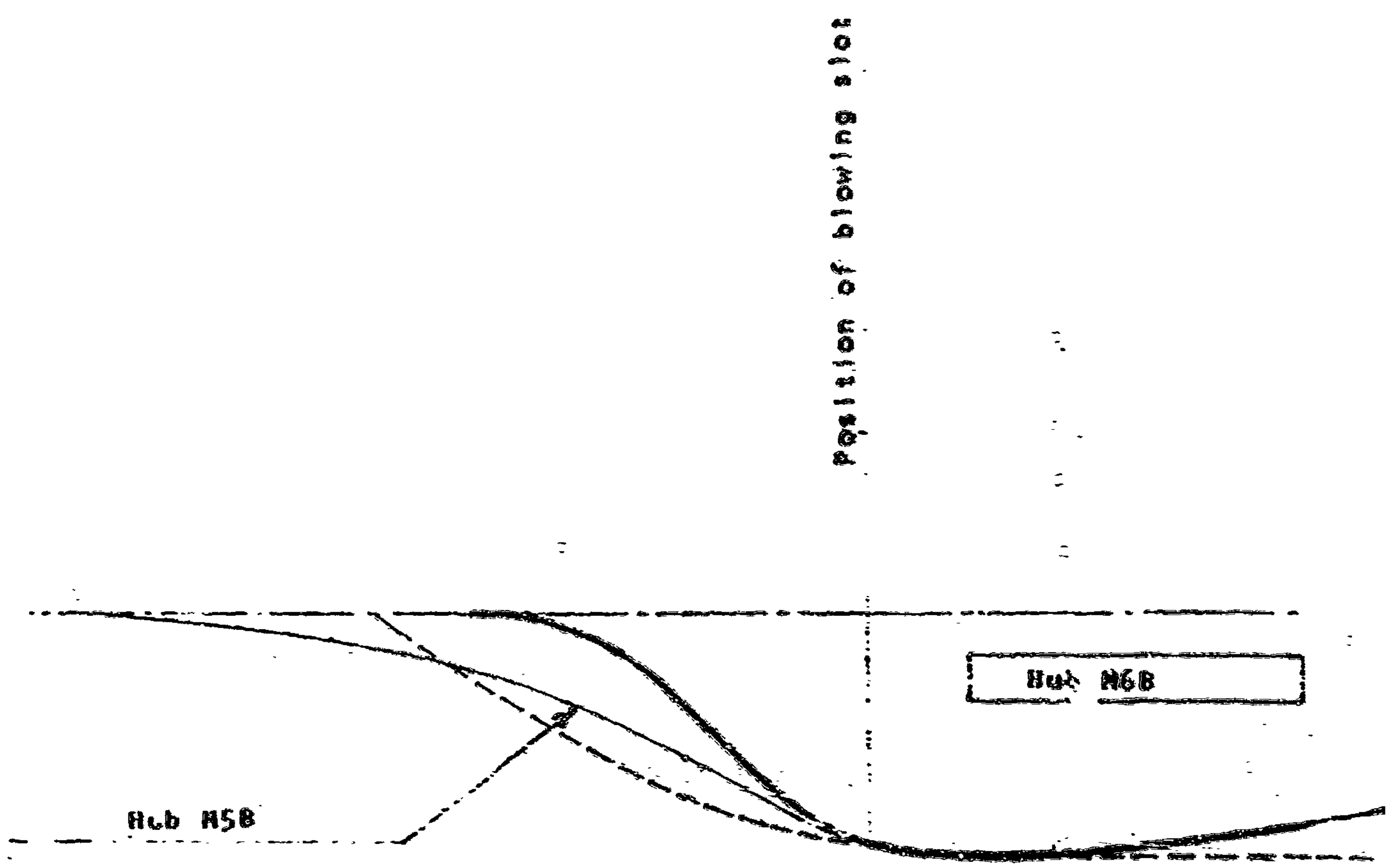


Plate V. Comparison of Hubs;

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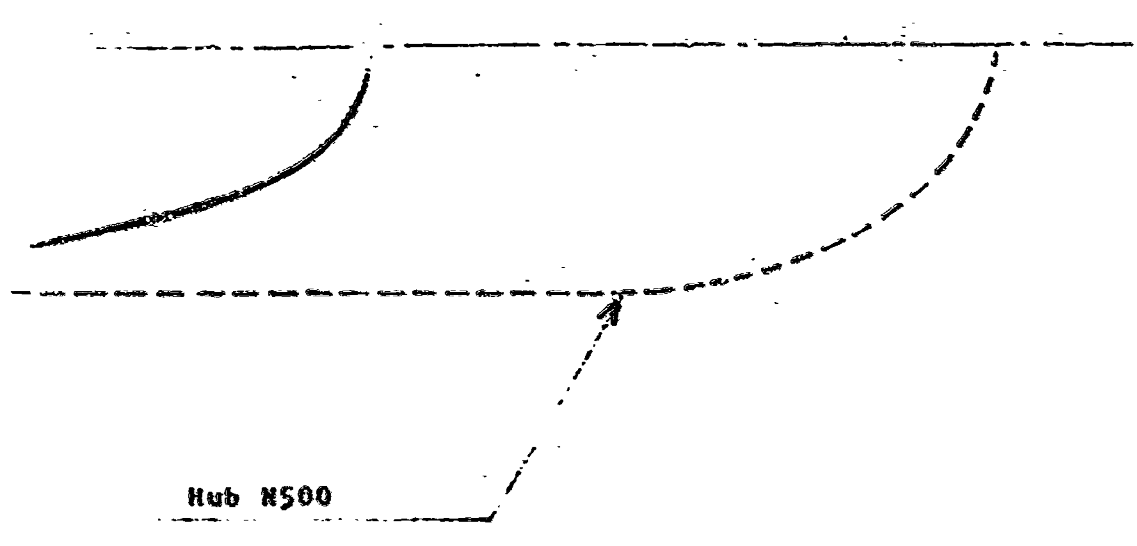

: ϕ = 682 mm Model.

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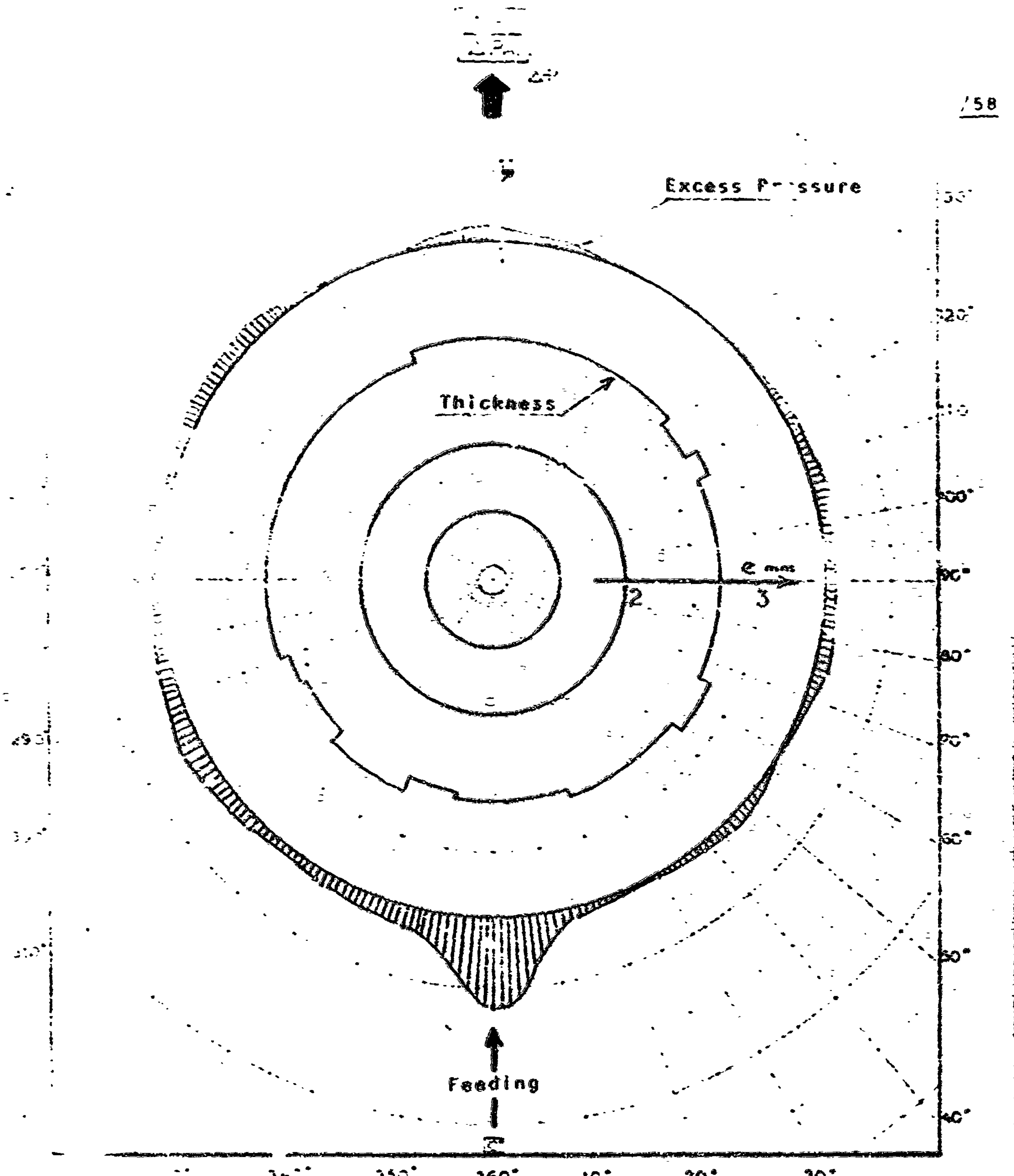


Plate VI. Azimuth. . . riation in Slot Thickness and in Excess R. . . . .essure; ϕ = 682 mm Model.

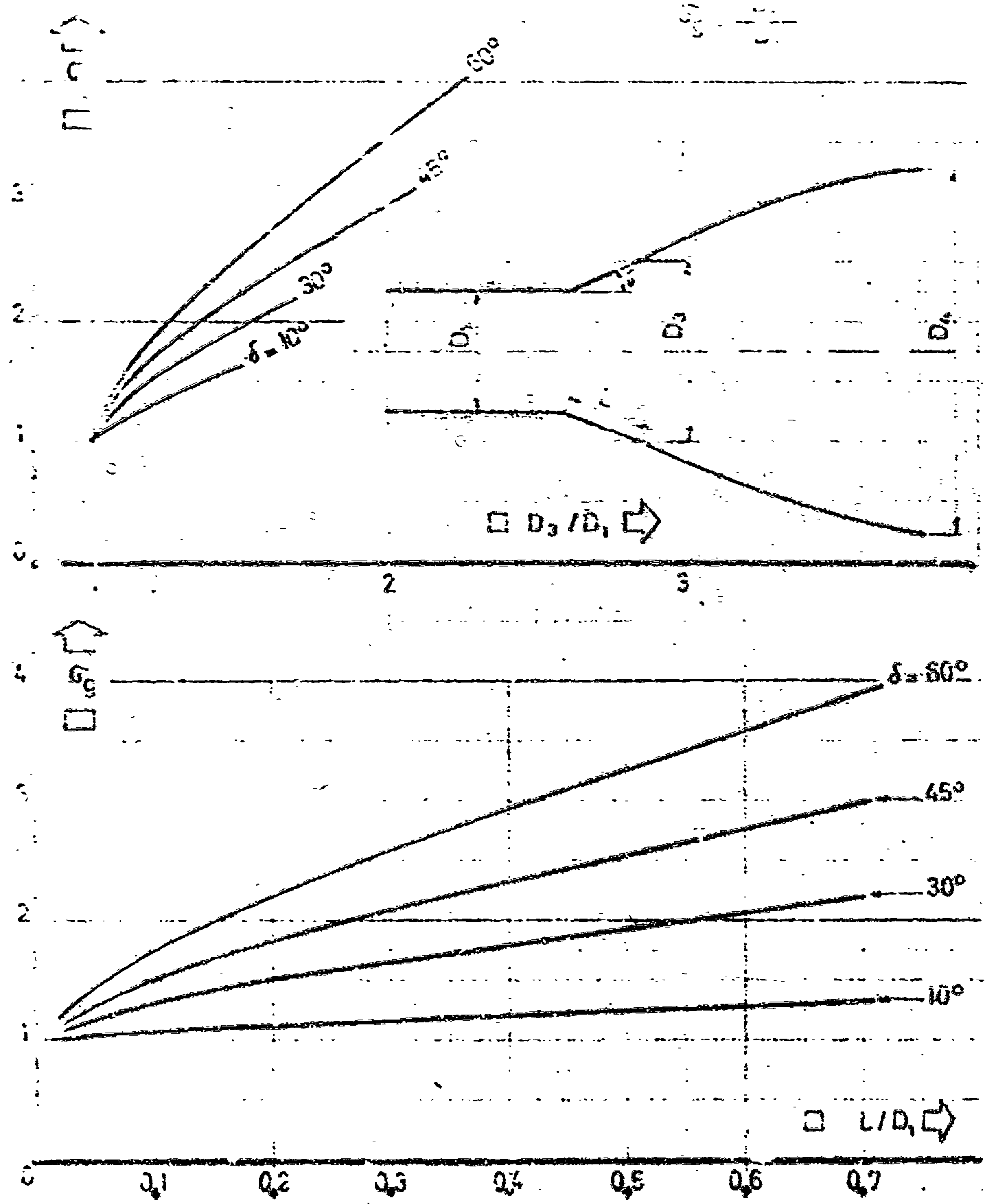
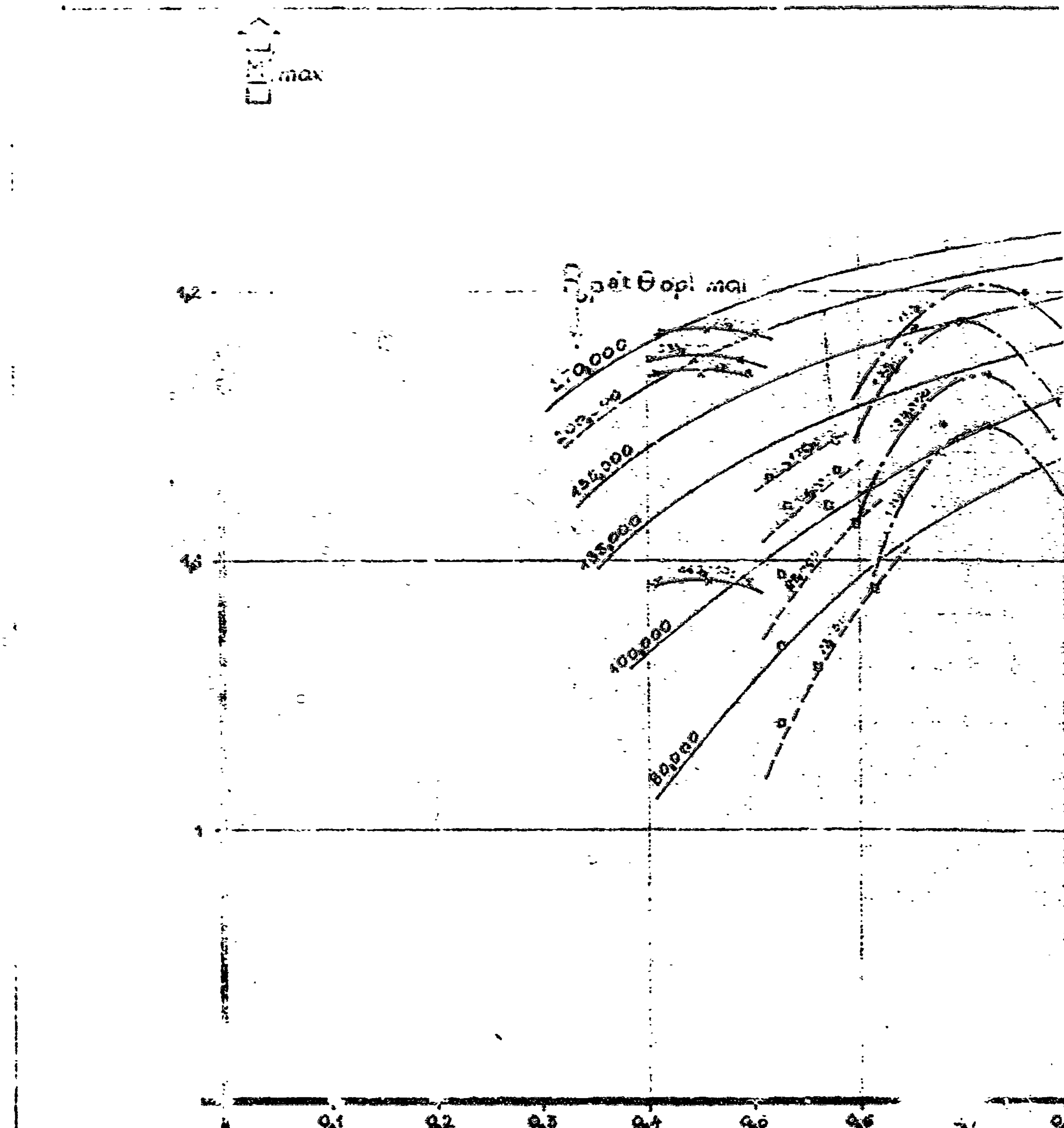
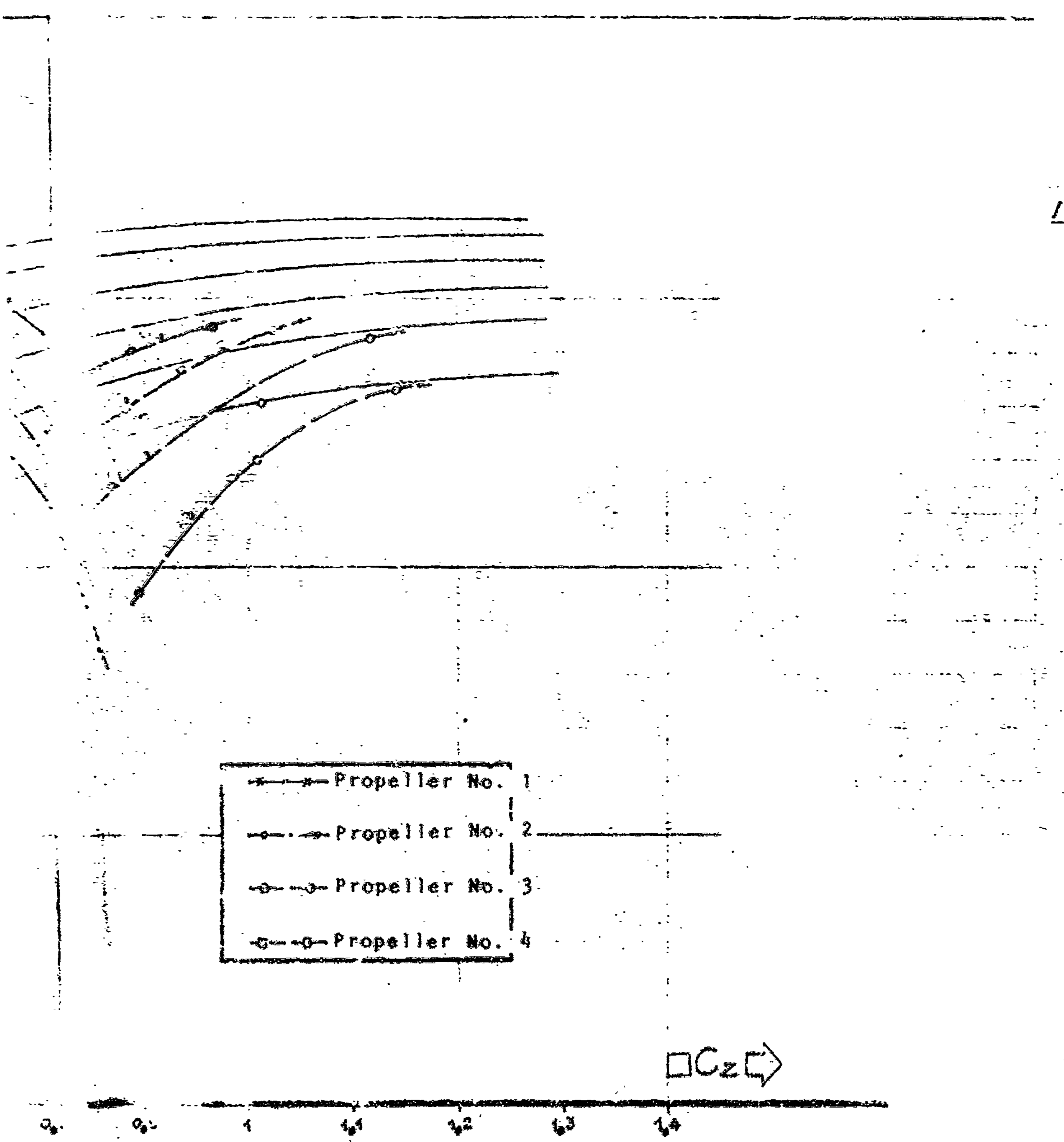


Plate VII. Geometric Diffusion in Irrotational Plane Flow (Ideal Incompressible Fluid). Theoretical Studies (SIDEM RE 102).



?late VIII. Influen(of Cz on N'_{1max}



`z anc of Peripheral Reynolds Number
= 620 mm Model "S".

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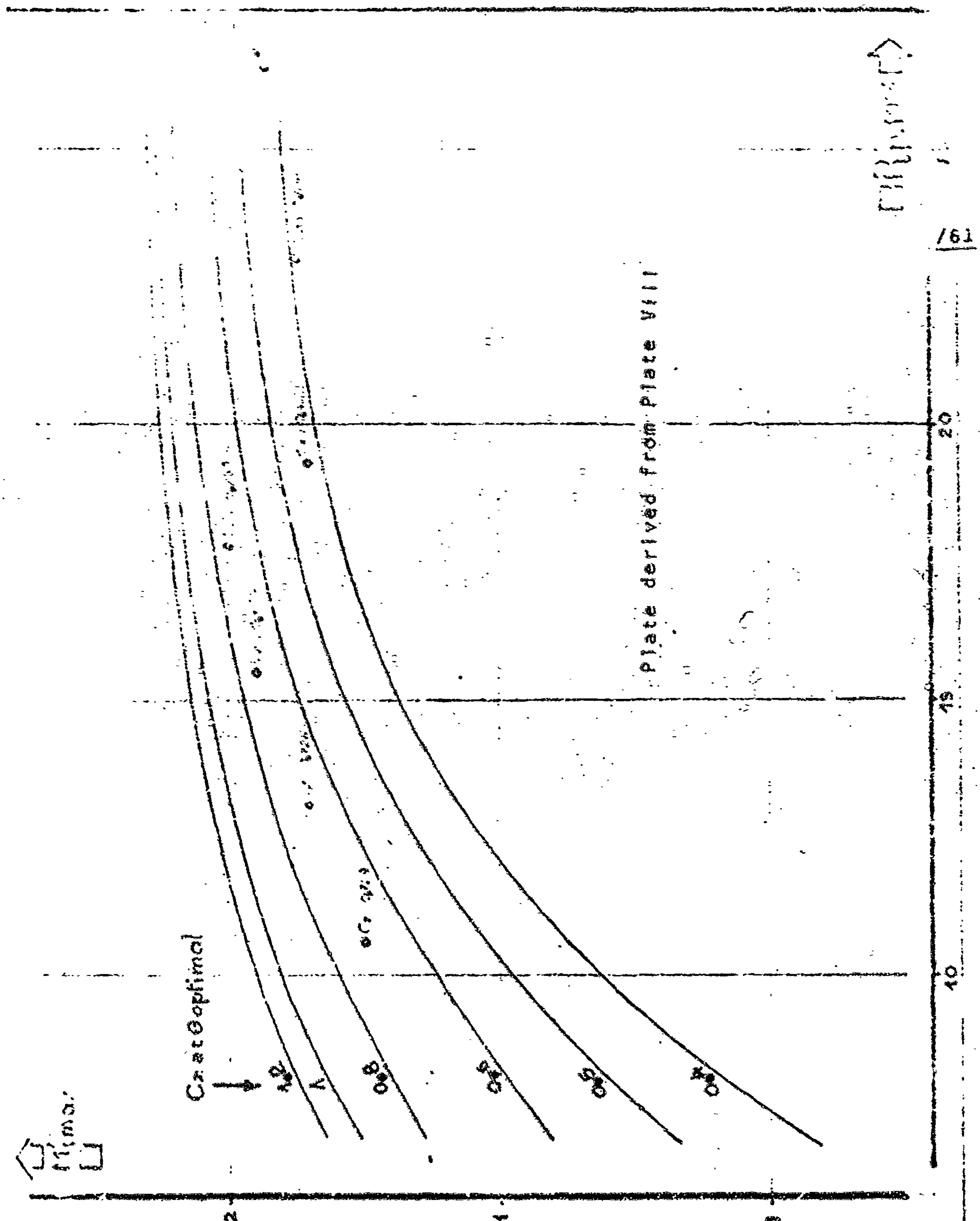

Plate IX. Influence of the Cz of Adaptation and the Peripheral Reynolds Number on M'_{1max}; D = 682 mm Model.

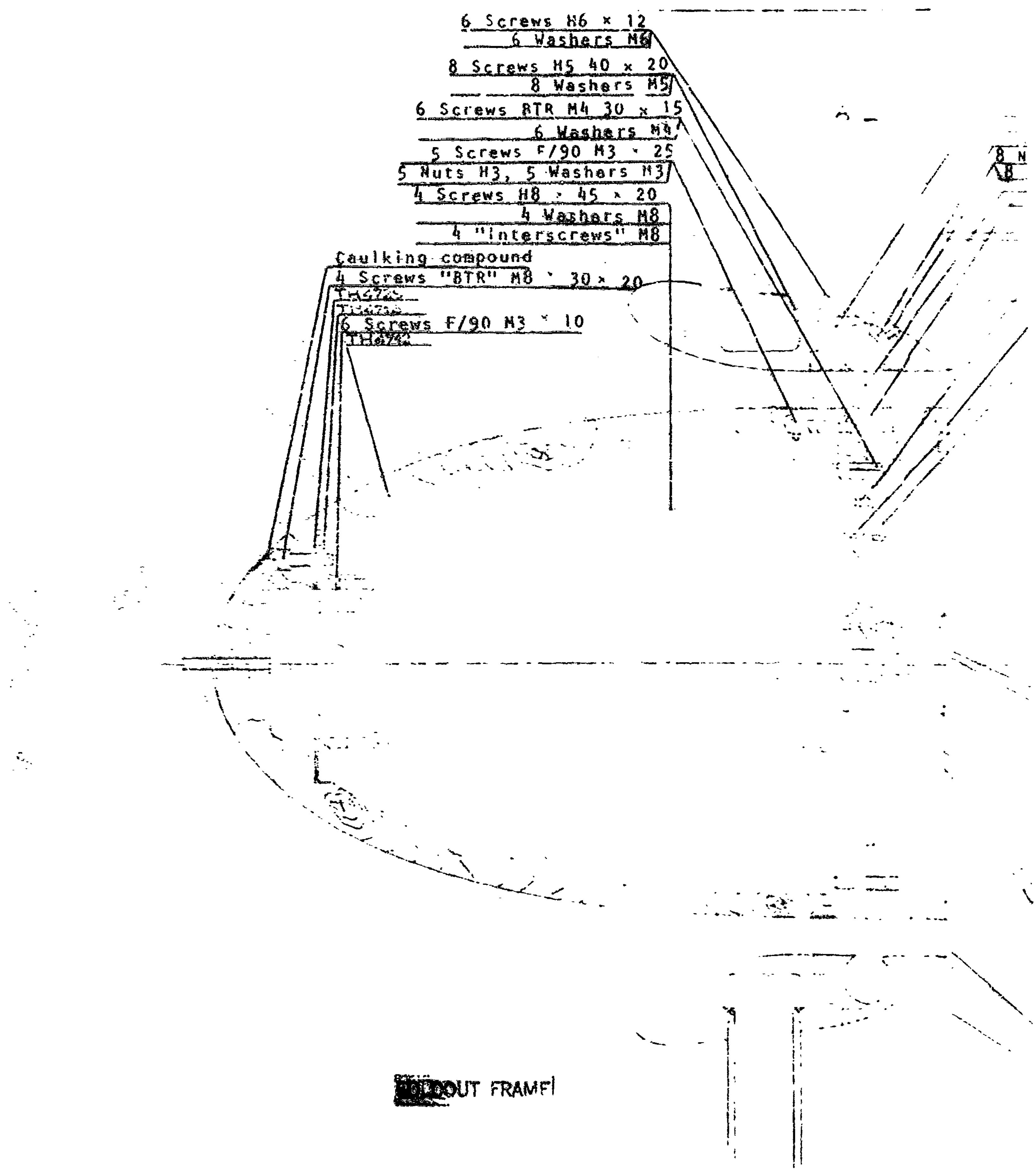

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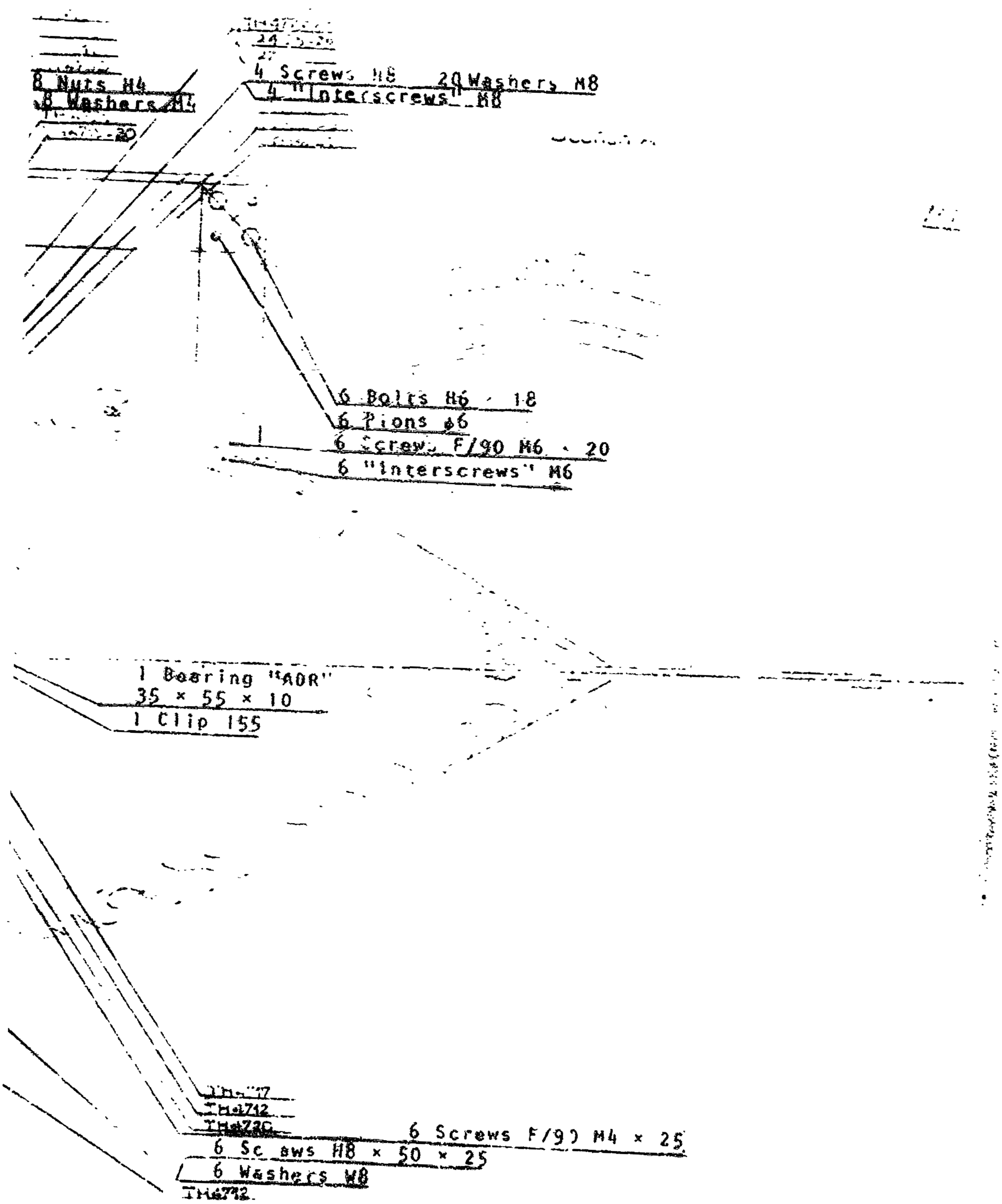
Plate X. Study Model of an Aerodynamic S



ic Gland at the Blade Tip.

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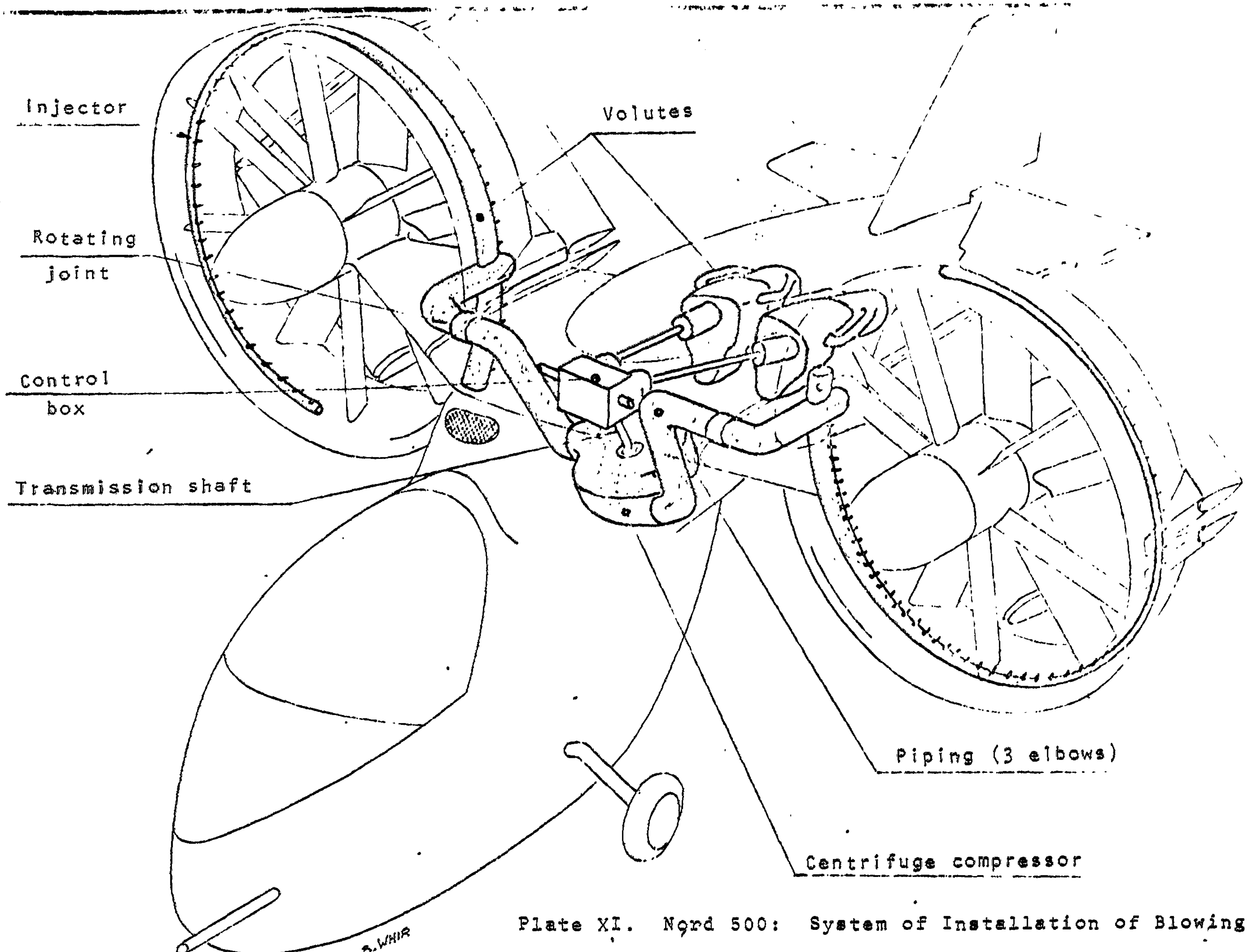
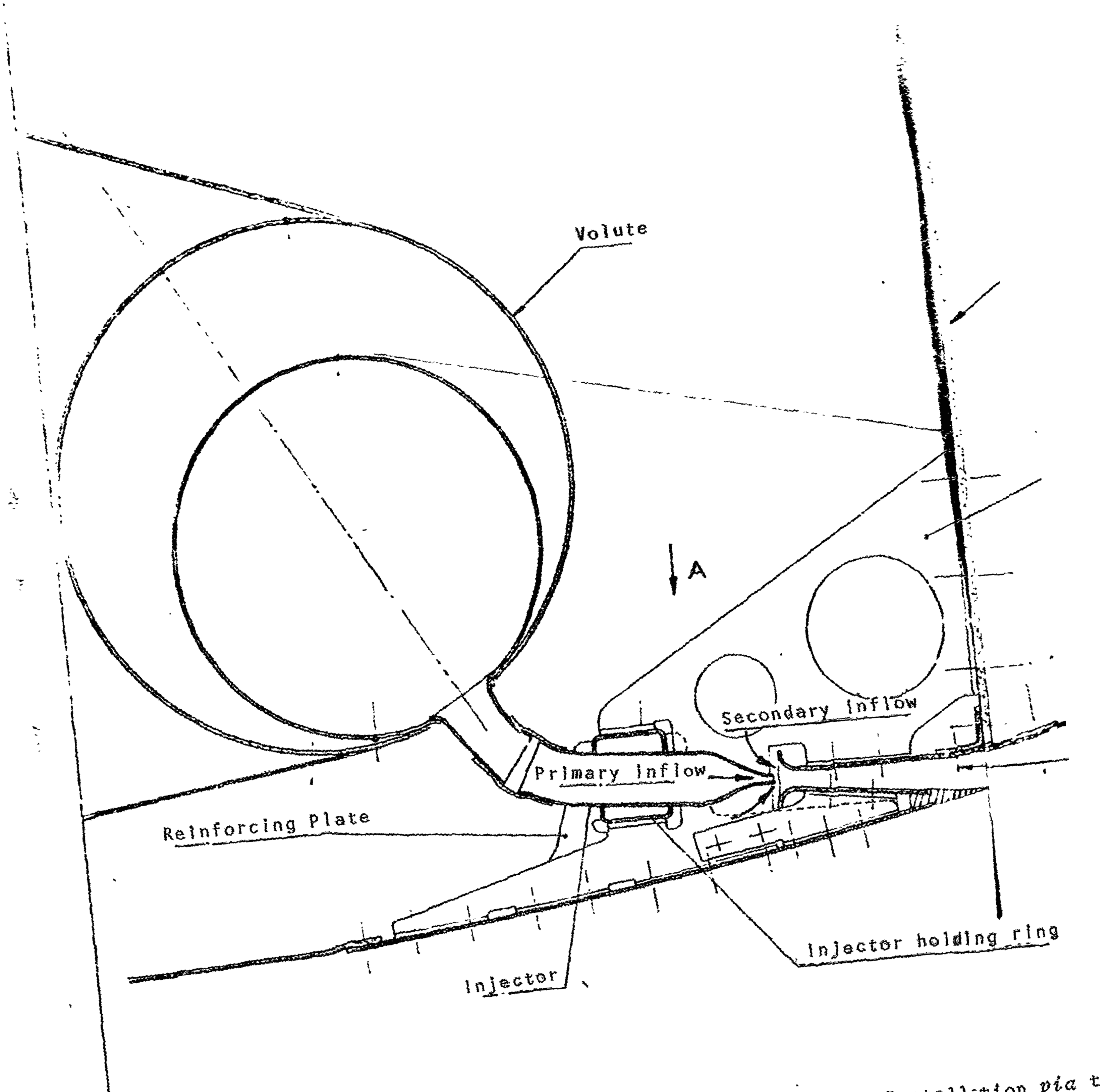


Plate XI. Nord 500: System of Installation of Blowing.



Scale: 1 Nord 500 aircraft

Plate XII. Blowing Installation *via* t

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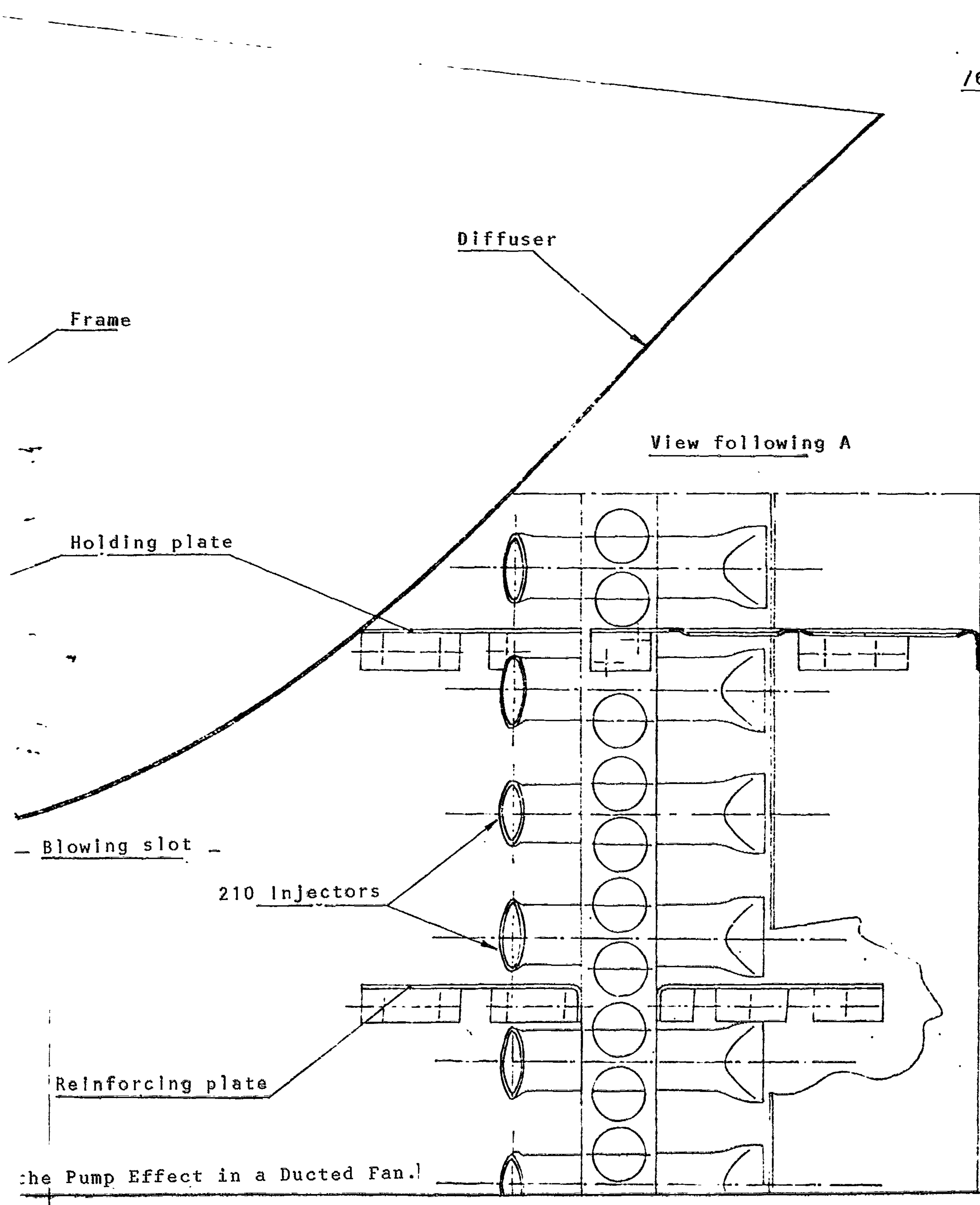


:he Pump Effect in a Ducted Fan.]

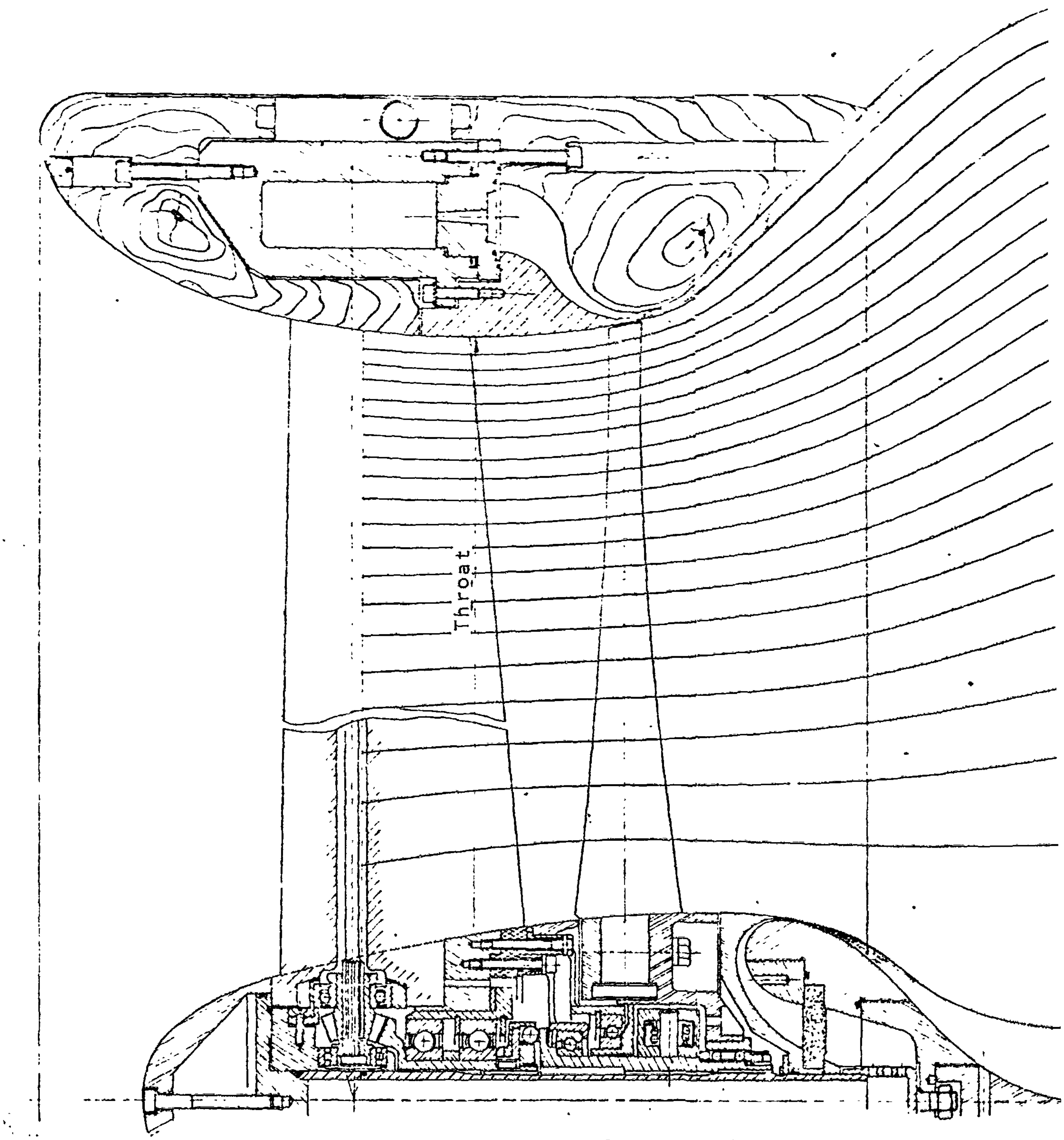
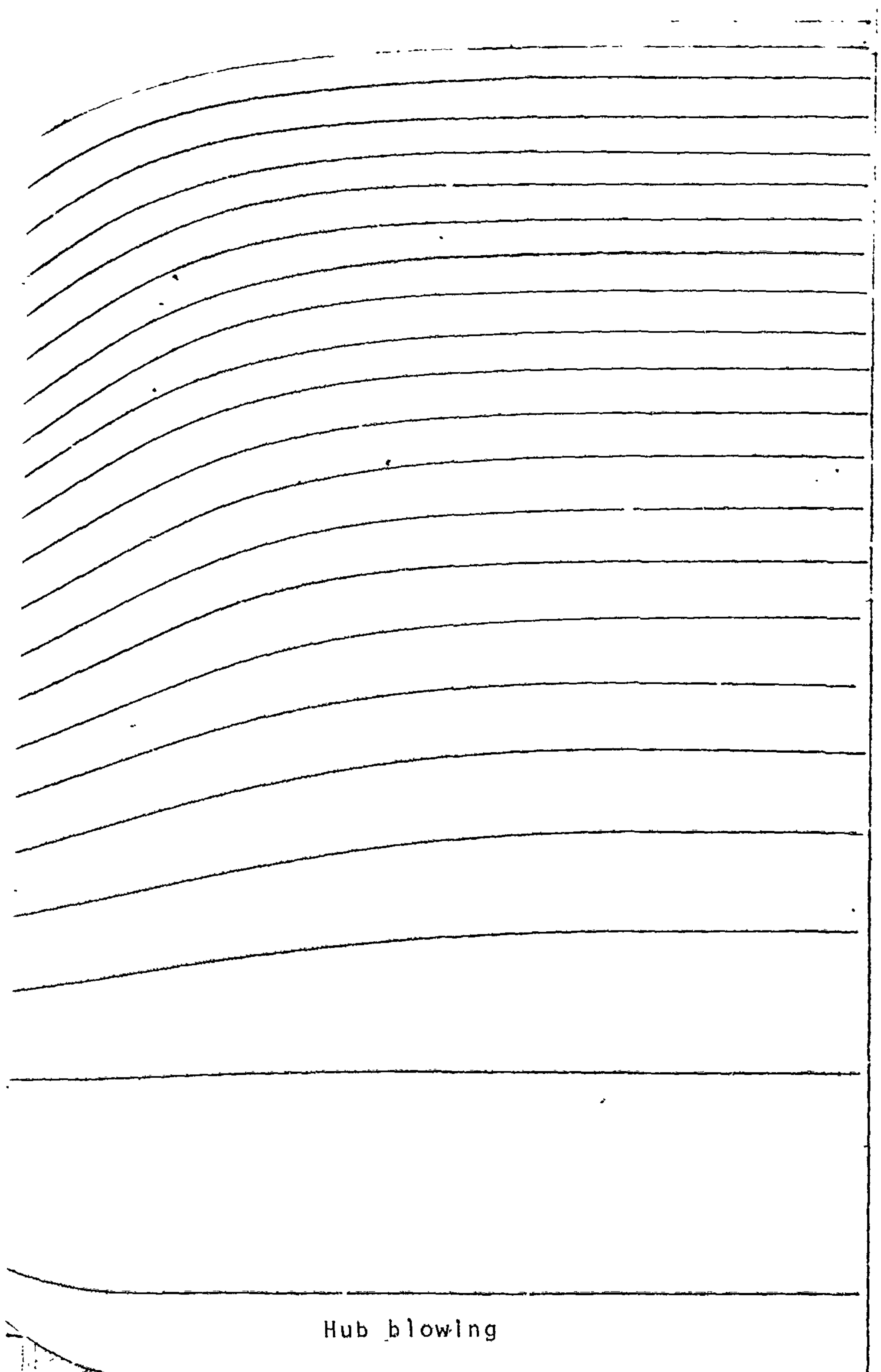


Plate XIII. Fields of Current Lines Sepa
Rings; ϕ = 682 mm Model (Cs $\simeq$ 15%;

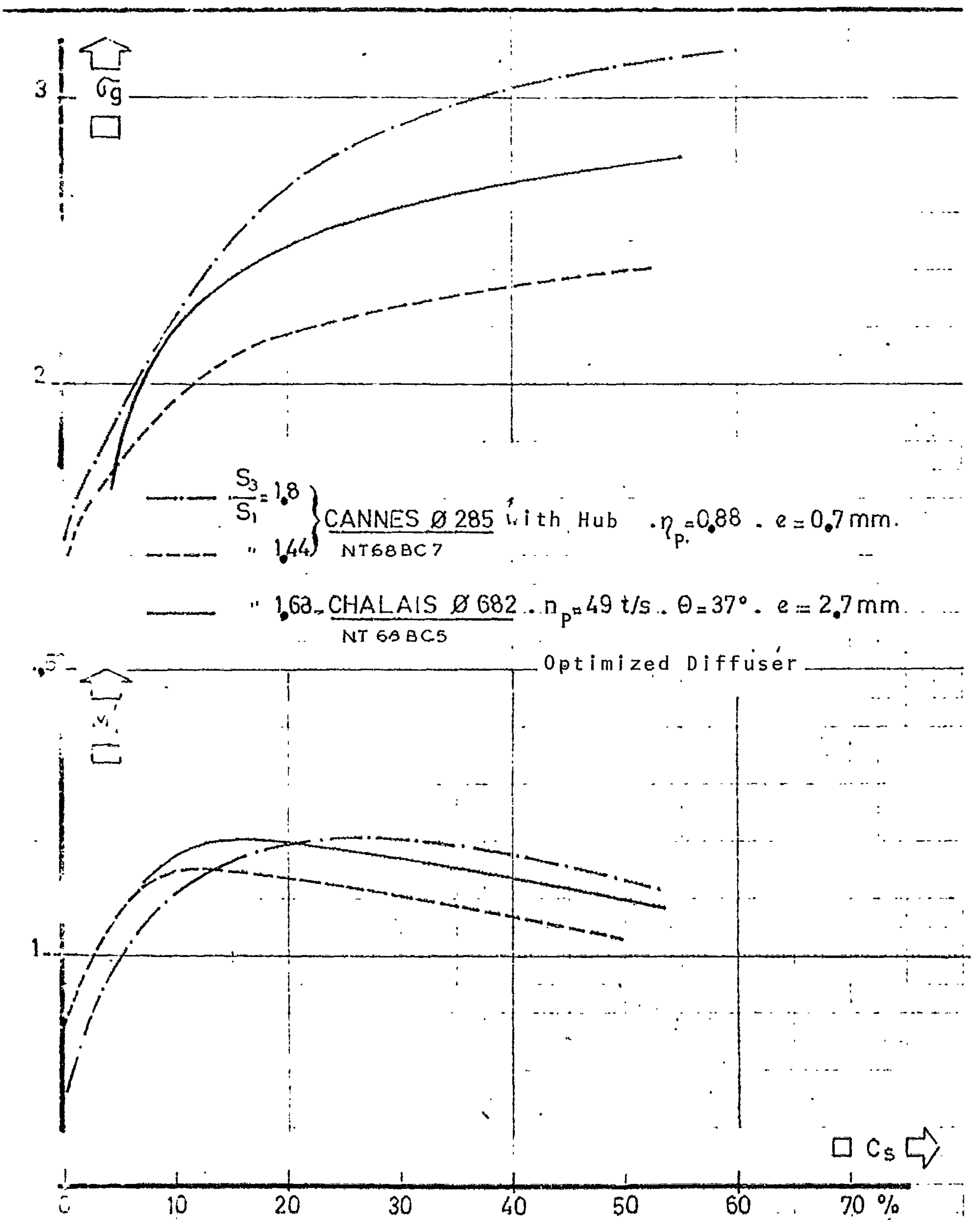
FOLDOUT FRAME

/65



es Separating Equal Output
≃ 15%; σ_g = 2.24).

FOLDOUT FRAME 2



/66

Plate XIV. Influence of the Blowing Rate: Value Number and Geometric Diffusion (Slot, 15°; Diffuser, 45°).

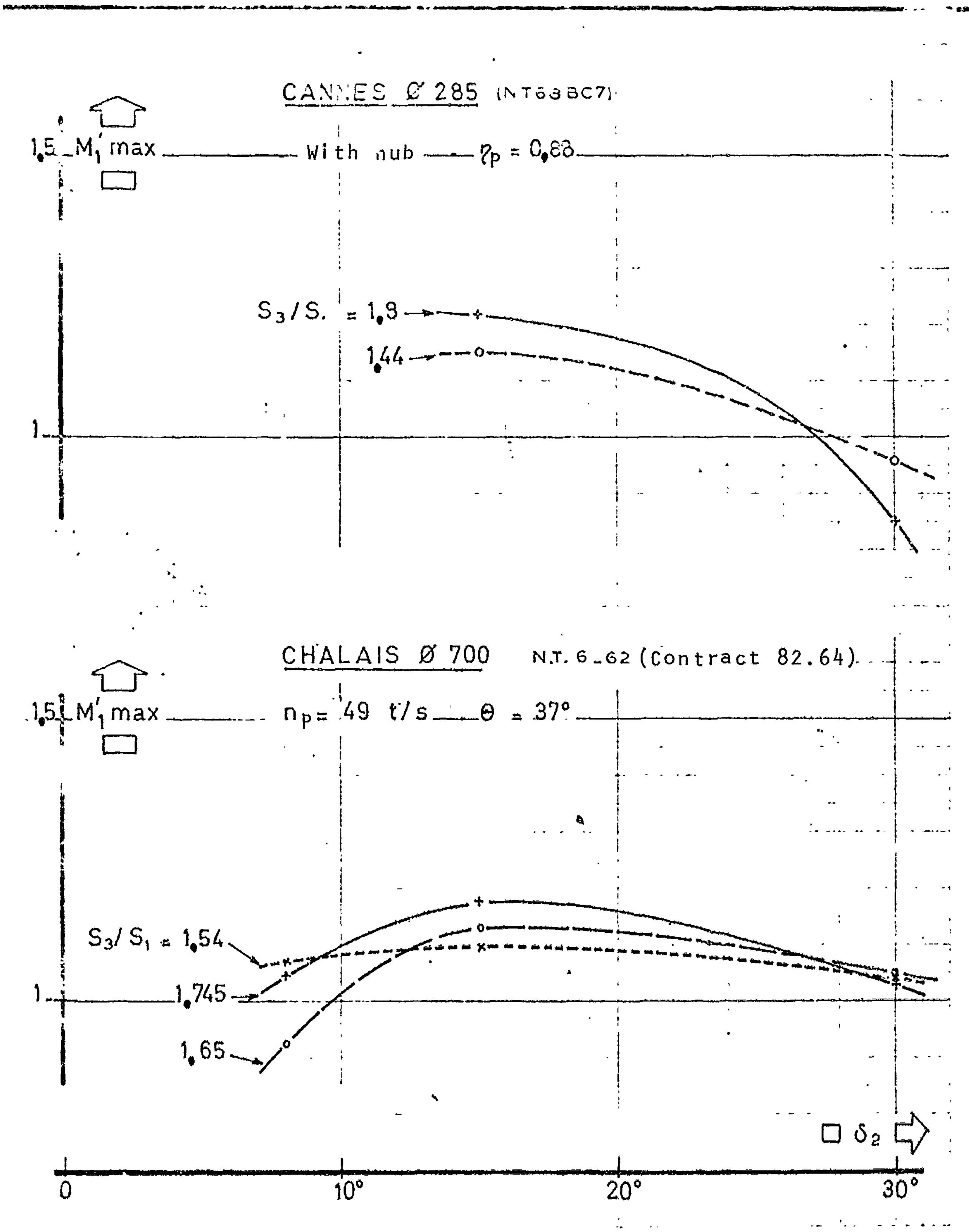


Plate XV. Influence of Slot Position: Value Number (Diffuser, 45°).

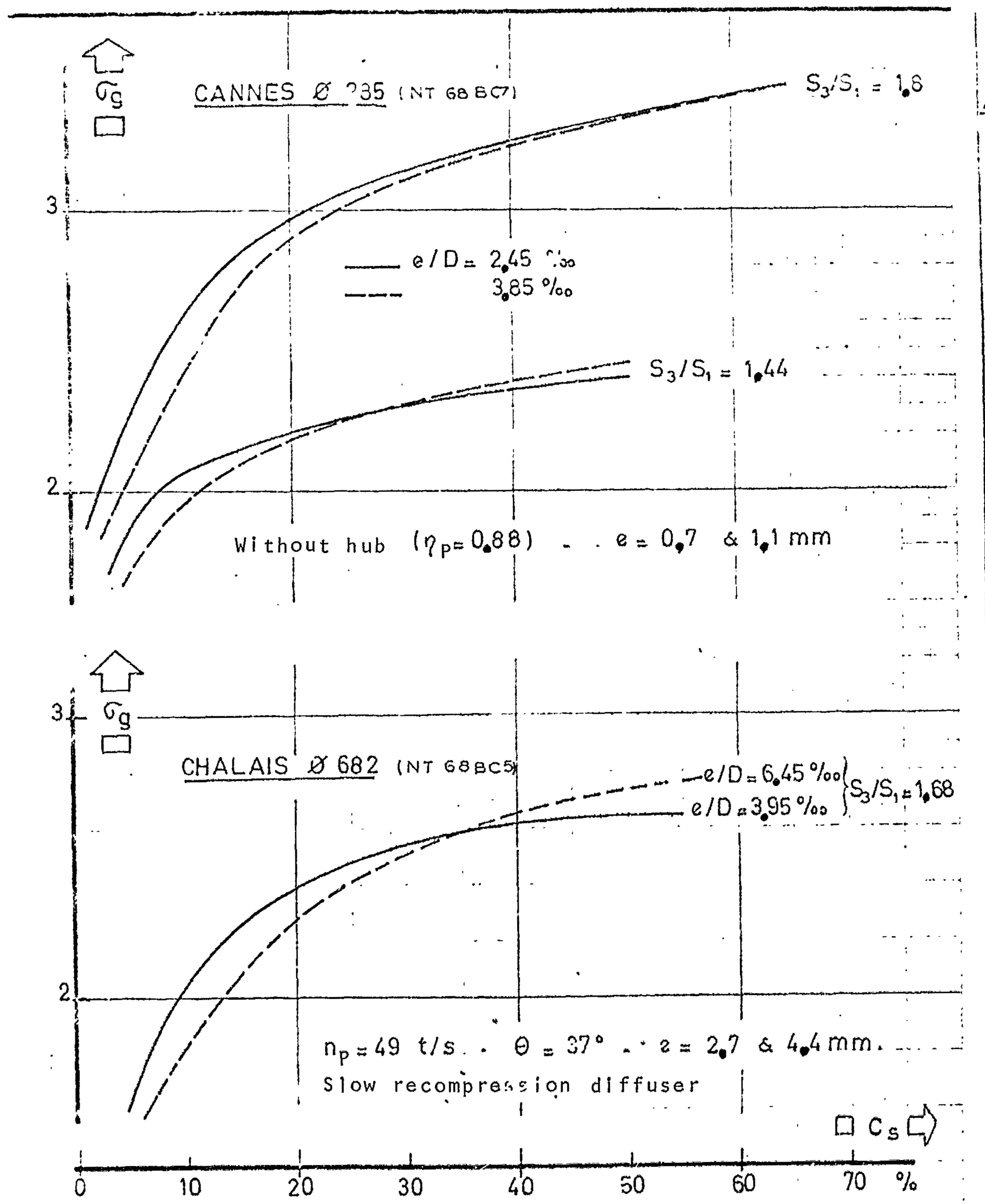


Plate XVI. Influence of Slot Thickness.
Geometric Diffusion (Slot, 15°, Diffuser, 45°).

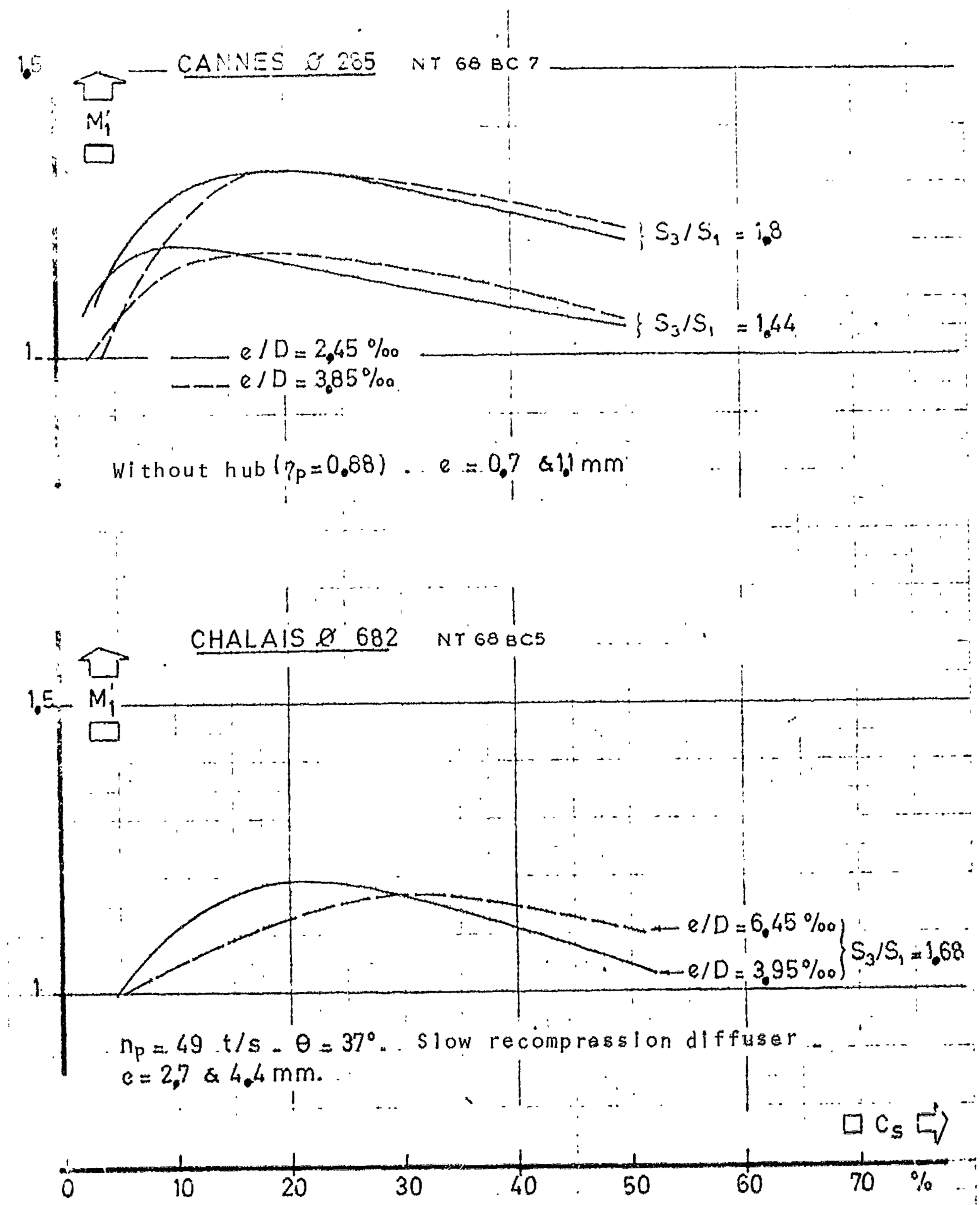


Plate XVII. Influence of Slot Thickness.
Value Number (Slot, 15°; Diffuser, 45°).

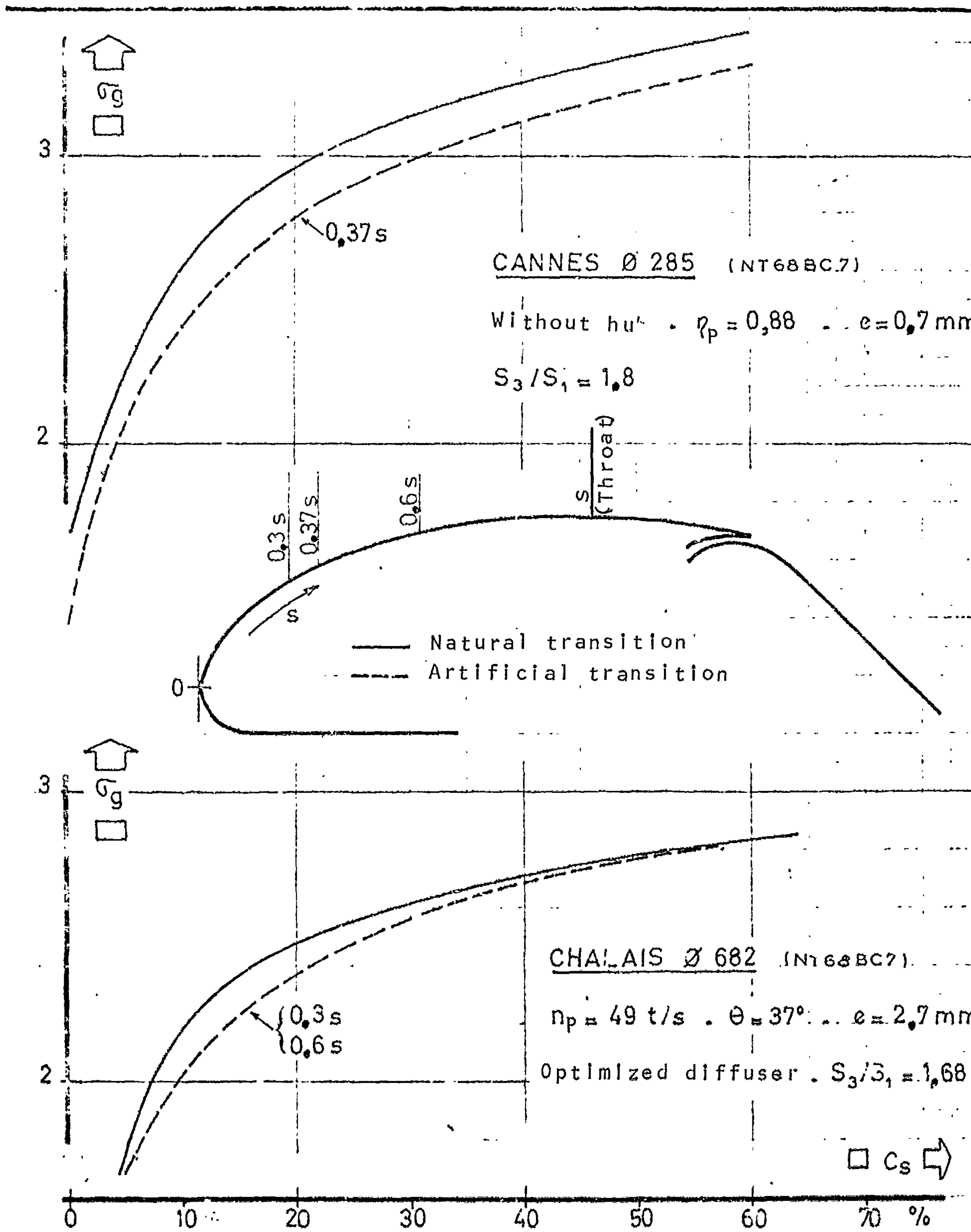


Plate XVIII. Influence of the Transition; Geometric Diffusion (Slot, 15°, Diffuser, 45°).

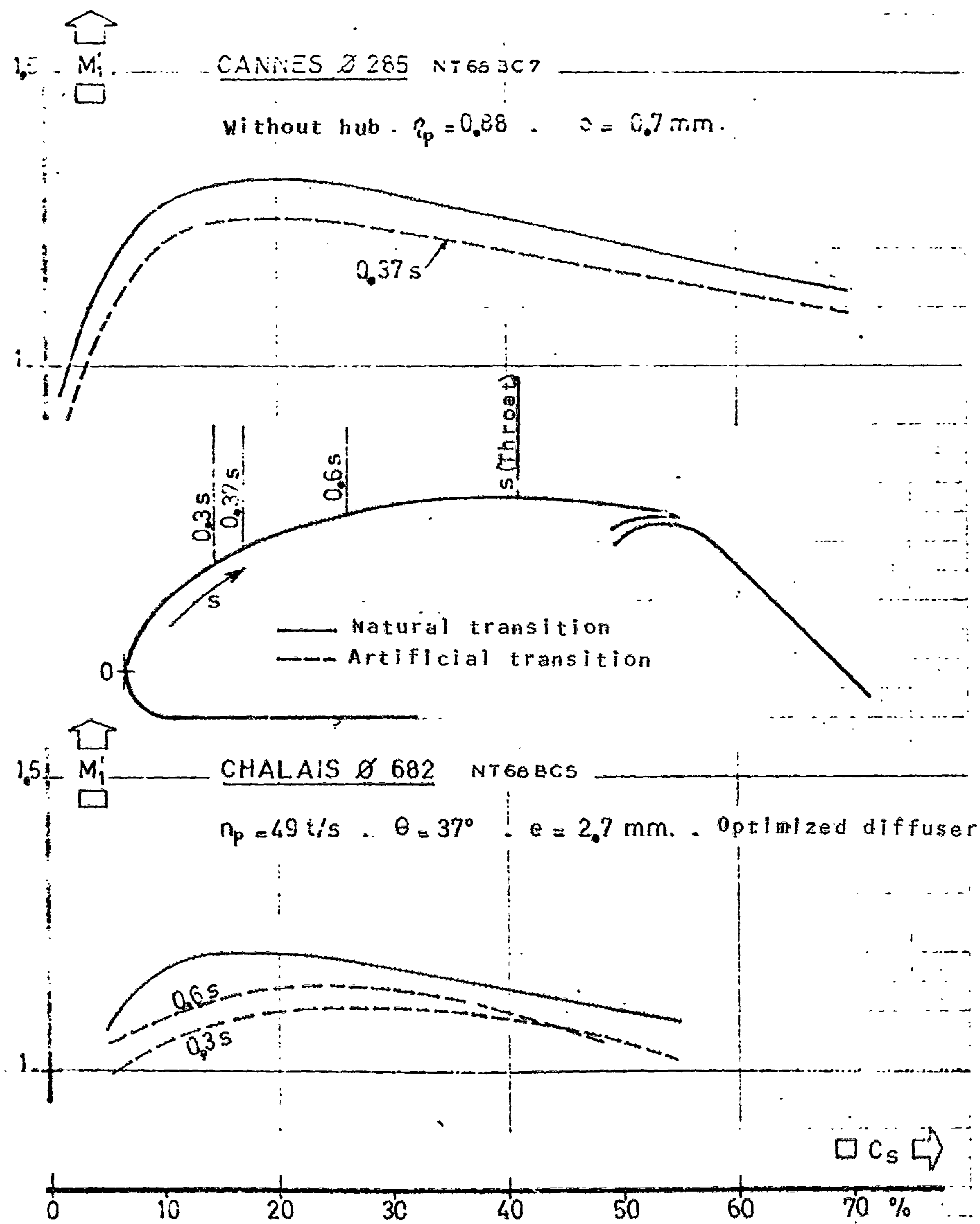


Plate XIX. Influence of the Transition; Value Number (Slot, 15°; Diffuser, 45°).

/72

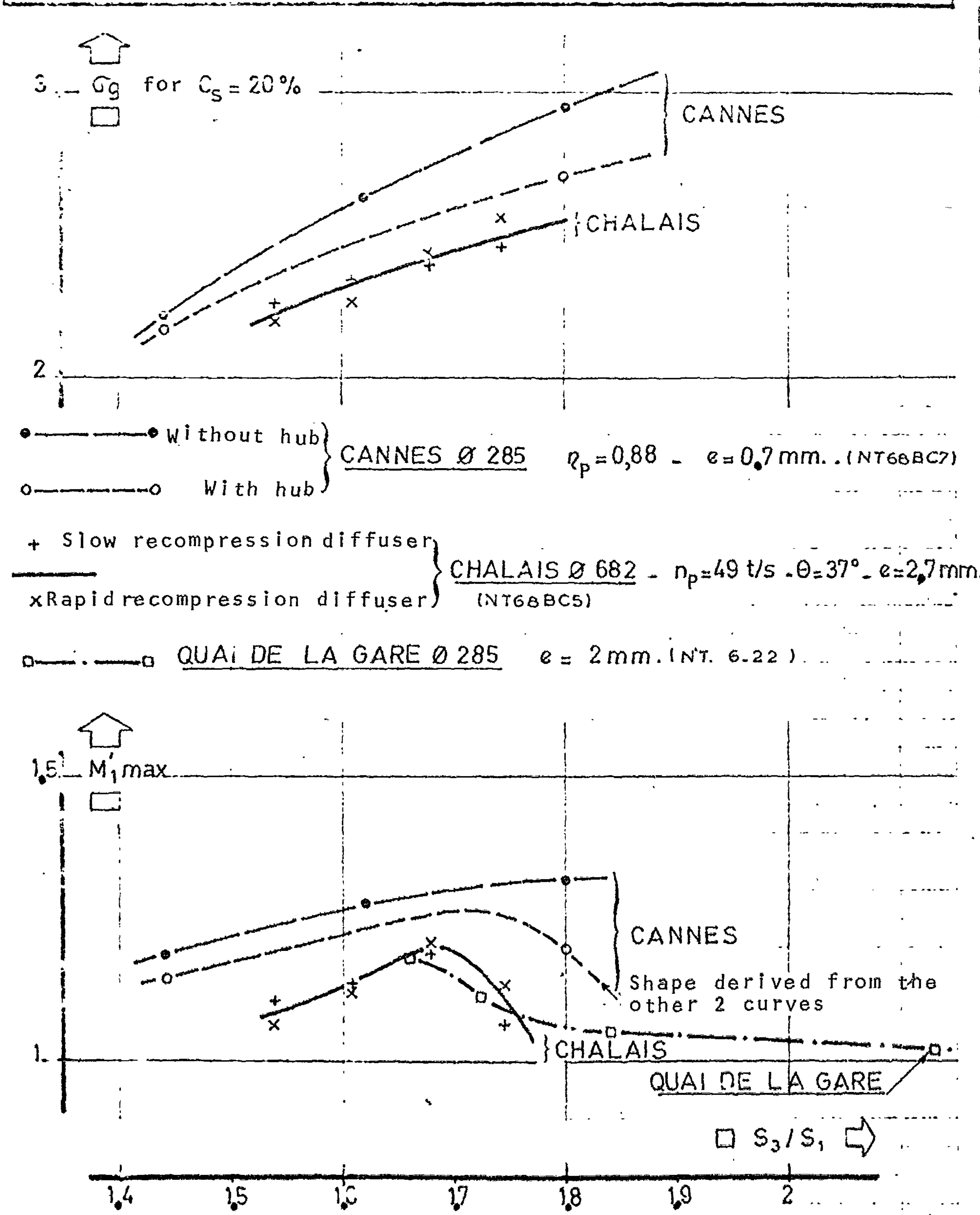


Plate XX. Influence of Diffuser Exit Section; Value Number and Geometric Diffusion (Slot, 15°; Diffuser 45°).

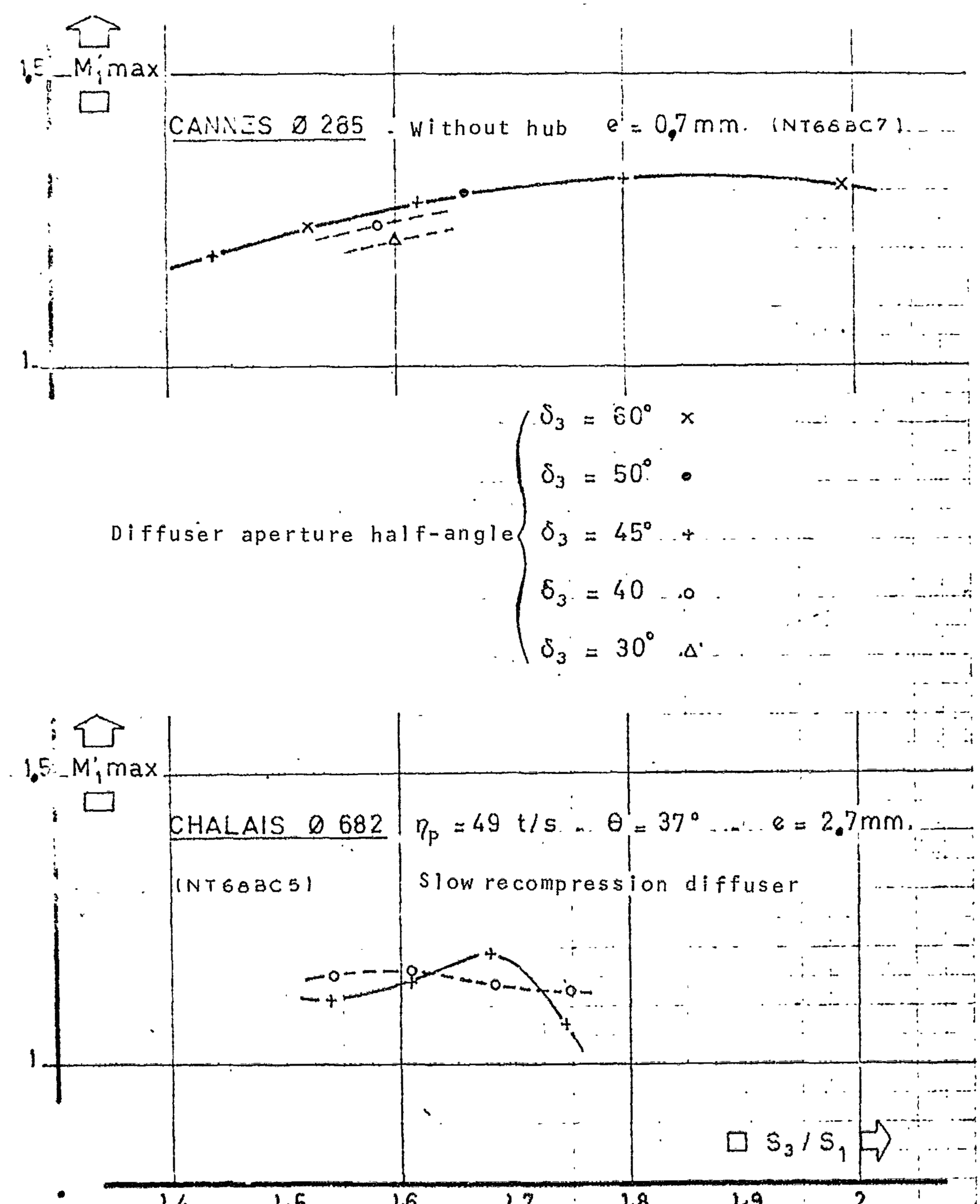


Plate XXI. Influence of Diffuser Aperture; Value Number (Slot, 15°).

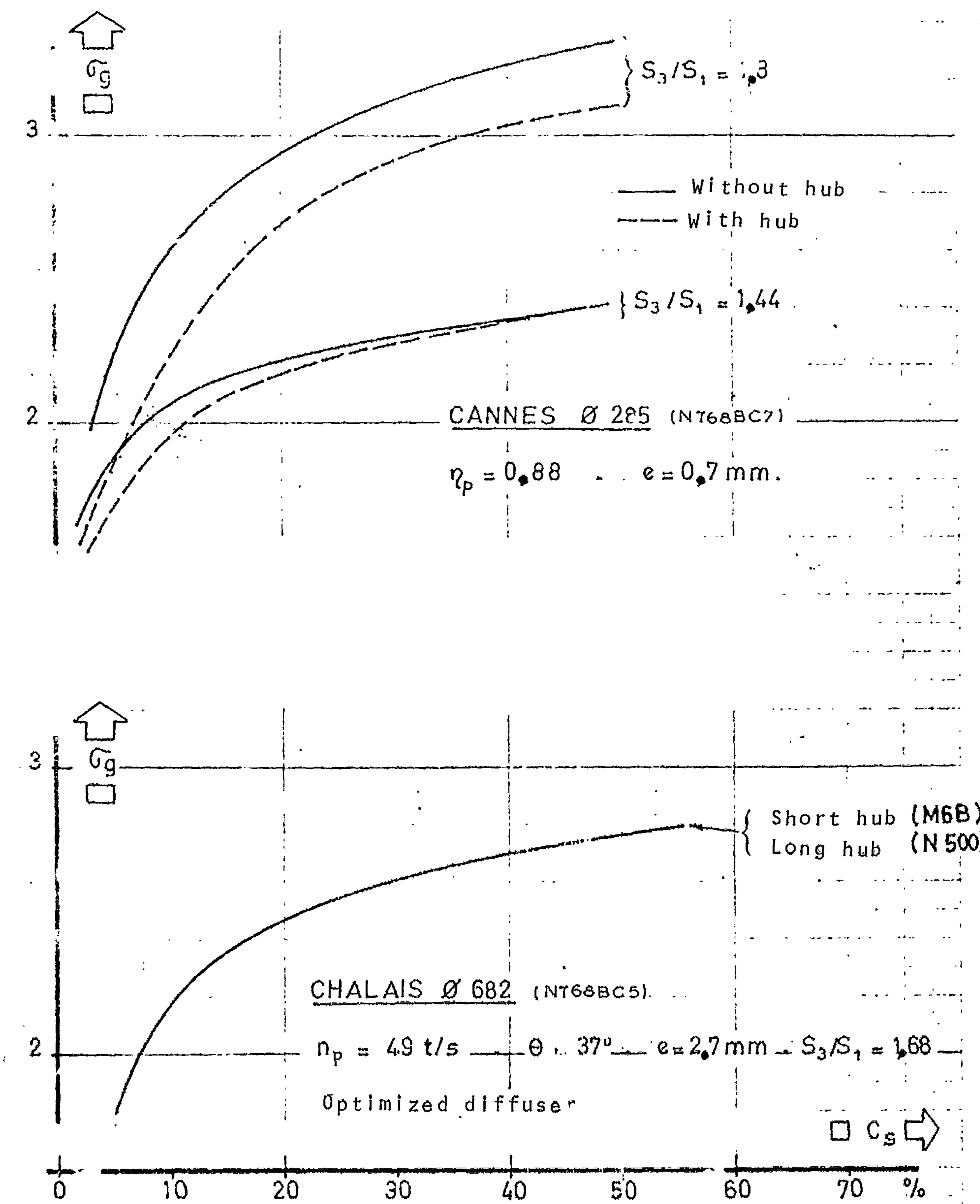


Plate XXII. Influence of Hub; Geometric Diffusion (Slot, 15°; Diffuser, 45°).

/75

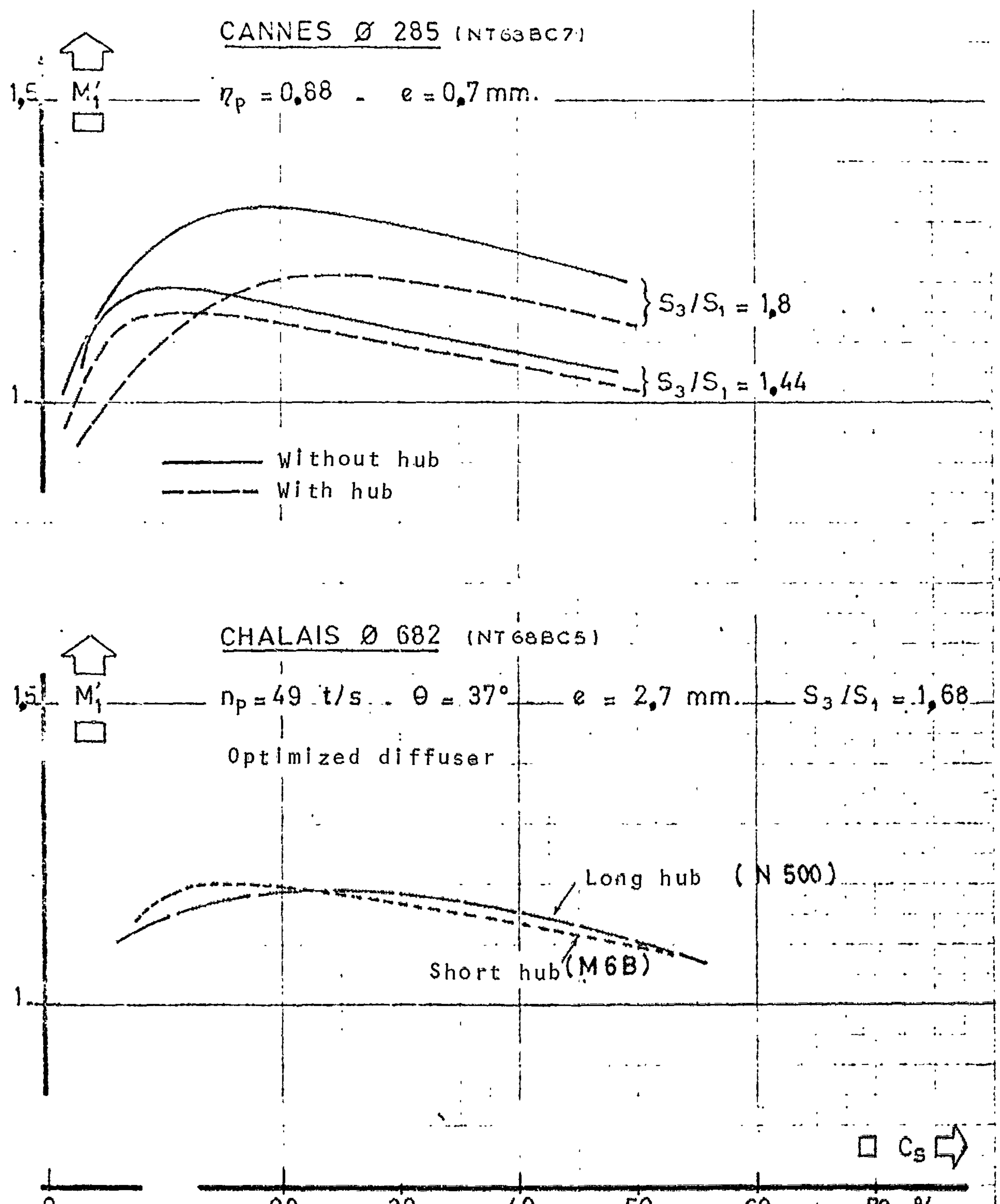


Plate XXIII, Influence of Hub; Value Number (Slot, 15°; Diffuser, 45°).

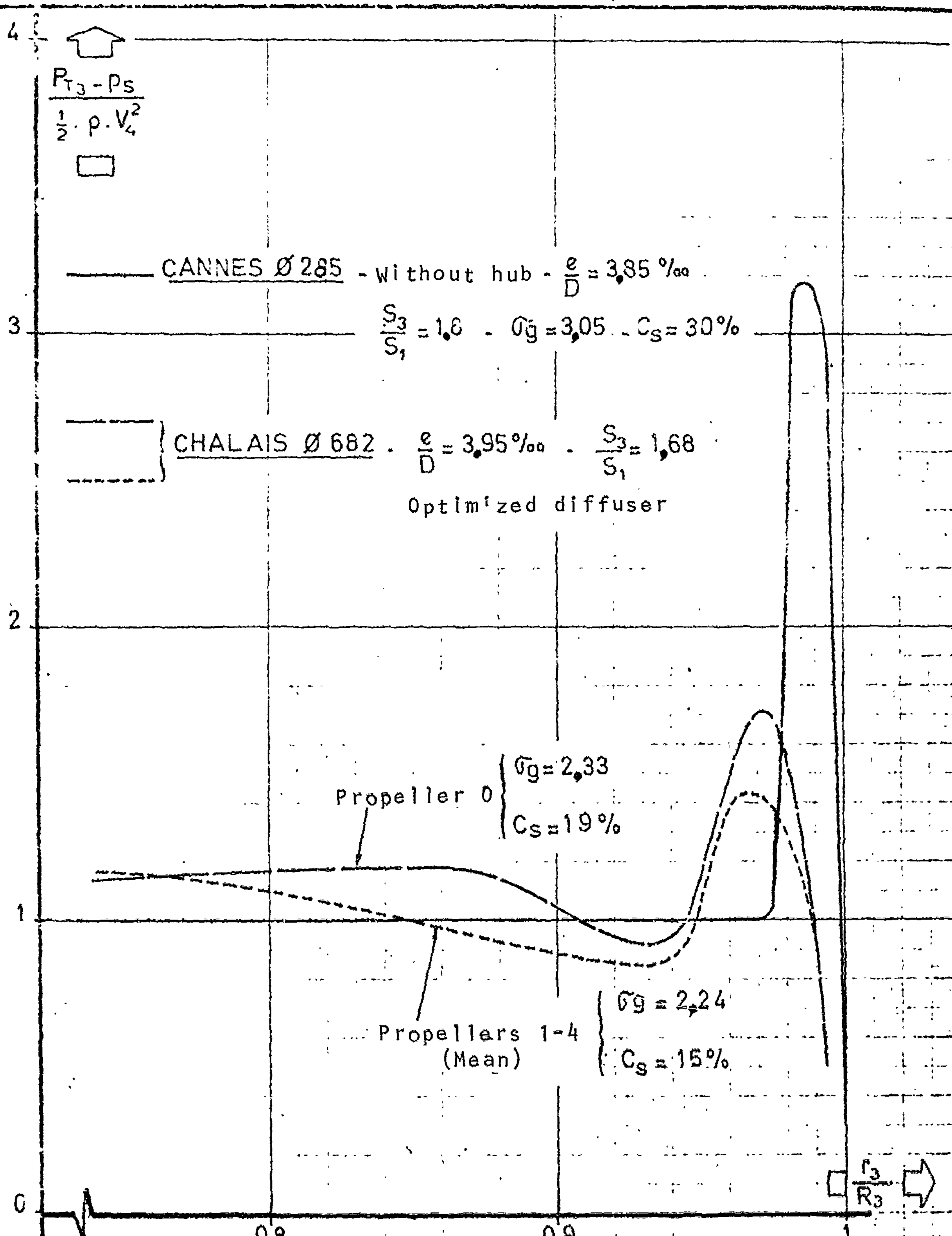


Plate XXIV. Blast Jet; Exit Plane of Diffuser (Slot, 15°; Diffuser, 45°).

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LIMITED DISTRIBUTION

ADDENDUM TO NT 68-Bc-17

DUCTED FANS WITH DOWNSTREAM DIFFUSION

DRME CONTRACT 27/67

Memo on Practical Application of Contract

Contract No. 27/67 (Order No. 7)

Number of pages: 7

Request No. 33-2-3468

Number of plates:

SOCIÉTÉ BERTIN & CIE

PLAISIR - (LES YVELINES) TELEPHONE 462-25-00

(a) OBJECT OF THE STUDY

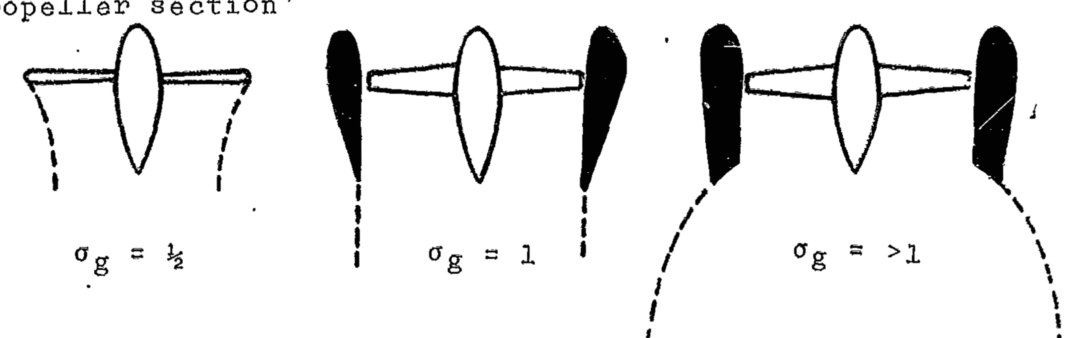
The study conducted under Contract 27/67 in collaboration with Nord-Aviation involved the investigation of high efficiencies of relatively short ducted rotors in the presence of considerable downstream diffusion. It followed the work under Contract 82/64. /1

Theory of the Ducted Rotor with Diffusion

The thrust of an engine is determined by the flow in the downstream section of the jet; the specific thrust T/W (ratio of thrust T to available power W) is all the greater as the final exhaust velocity nears the speed of transfer of the engine.

Therefore, there is interest in increasing the downstream section of the jet; this can be accomplished using a ducted fan with diffusion while, in contrast, the jet behind a free propeller is closed.

$$\sigma_g = \frac{\text{downstream section}}{\text{propeller section}}$$



Free propeller (fixed-point) | Ducted fan without diffusion | Ducted fan with diffusion

In fact, obtaining significant diffusion makes it necessary to combat the tendency toward separation of the flow on the diffuser wall in the presence of a boundary layer. The diffusion is worthwhile only if it can be obtained economically.

(b) ORIENTATION GIVE BY DRME

Ducted rotors with downstream diffusion are designed to support and propel VTOL aircraft economically, as well as for supporting /2 platforms (radar mountings, anti-submarine warfare systems, etc.).

The normal end result of the research projects entrusted to the Société Bertin is to transfer the results and knowledge acquired to a firm which has the industrial means to construct these test models, and then operational vehicles.

(c) CHRONOLOGY OF THE OPERATIONS

Contract 27/67 was confirmed on June 23, 1967.

--June 67 to December 67:

- preparation of the work and modification of the models;
- theoretical study of fixed-point diffusion in two-dimensional flow.

--November-December 68:

- fixed-point optimization tests on a ϕ = 700 mm model at Chalais-Meudon.

--January 68:

- tests on a ϕ = 285 mm model at the Cannes wind tunnel.

--January-March 68:

- fixed-point experimental study of the propeller on a /3 ϕ = 700 mm model at Chalais-Meudon.

--February 68:

- tests of an aerodynamic gland at the blade tip on a ϕ = 400 mm model at the fixed-point test stand in Saint-Cyr.

--January-July 68:

- theoretical studies, practical application and various studies.

--July-October 68:

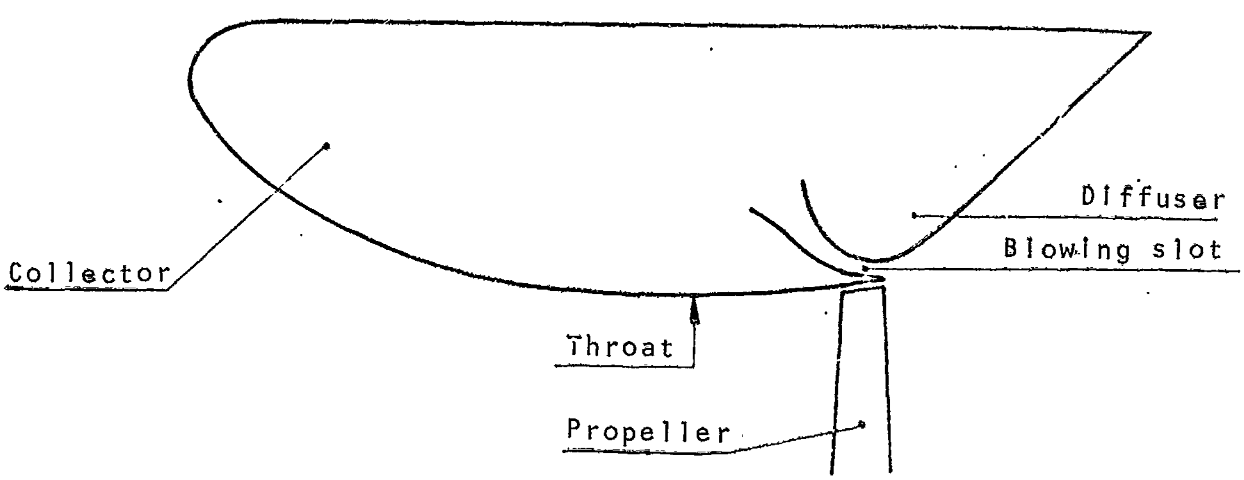
- digest report on the research.

(d) SITUATION AT THE BEGINNING OF THE CONTRACT AND OBJECTIVES OF THE RESEARCH

Studies carried out by the Société Bertin before October 1962 had made it possible to approximately define an interesting base system.

The solution kept involves a shroud defined by a rheoelectric cell capable of ensuring acceleration in the boundary layers as far downstream as possible up to a blowing slot with a short, wide-open diffuser (half-angle ≃ 45°).

/4



Promising results had been obtained in the fixed-point case on a small scale. Contract 82/64 (October 1962-February 1967) made it possible to perfect models on a normal scale, to extend the study of the influence of various parameters, to carry out tests by translation and by oblique incidence, to develop studies of the shroud using an analogical method and to undertake theoretical studies.

The objectives of Contract 27/67 were to pursue a course for perfecting short diffusion behind a ducted fan. The lines of action chosen were the following:

- --progressive development of a complete mathematical model of the flow by operating through increasing complexity;
- --research of solutions to the problem of feeding the blowing slots on a flight vehicle;

--extension of knowledge relative to internal operation and free diffusion;

--optimization of the configuration developed in earlier research;

--determination of the influence of propeller parameters; /5

--study of an aerodynamic gland at the blade tip based on the rotation of a vortex in a cavity located to the right of the blades to permit eliminating the problem of play at the blade tip.

(e) DEVELOPMENT OF THE STUDY

The study was broken down into seven parts:

(1) preparatory work;

(2) test series at the Cannes wind tunnel on a ϕ = 285 mm model;

(3) fixed-point tests on a ϕ = 700 mm model at Chalais-Meudon (optimization);

(4) theoretical studies (streamlines in two-dimensional flow, asymmetric shroud, work plan for obtaining a complete mathematical model);

(5) fixed-point experimental study of the propeller parameters on a ϕ = 700 mm model at Chalais-Meudon;

(6) experimental study of an aerodynamic gland at the blade tip;

(7) various studies (feeding the slots on an aircraft, critical study of performances, analysis of internal operation, synthesis of the projects).

(f) RESULTS AT THE END OF THE STUDY

The total performance obtained in the fixed-point case (M'_1 = value number) was slightly improved relative to earlier results (M'_1 = 1.20 instead of 1.17), and the corresponding blowing rate was essentially reduced (Cs = 16% instead of 24%).

Comparison with the corresponding values of a ducted fan without diffusion or of a free propeller is meaningful.

Ducted Fan with Diffusion	Real Performance	$M'_1 = 1.20$	$\sigma_g = 2.4$
Ducted Fan without Diffusion	Ideal Performance Real Performance	$M'_1 = 1$ $M'_1 = 0.85$	$\sigma_g = 1$
Free Propeller	Ideal Performance Real Performance	$M'_1 = 0.707$ $M'_1 = 0.5$	$\sigma_g = 0.5$

• The study of the influence of various parameters on performance was developed. In particular, propeller tests showed that the choice of propeller parameters considerably affected total performance although to a limited extent.

• Probing in the diffuser exit plane made it possible to establish that most of the blowing energy ($\simeq$ 70%) was dissipated between the slot and the exit plane.

• The preliminary project for installation of a compressor-pump system on a Nord 500 aircraft showed that the predicted gain in load corresponded to approximately 22% of the unloaded weight of the aircraft. /7

• Tests of an aerodynamic gland at the blade tip demonstrated the rotation of a vortex in the cavity located to the right of the blades and a certain degree of regeneration of the boundary layers.

(g) CONCLUSIONS--FINAL PERSPECTIVES

The body of progressively-obtained results is large and encouraging. The very interesting value of the value number realized in the fixed-point case (M'_1 = 1.2) will be difficult to exceed.

Exchanges of opinion with Nord-Aviation indicate that subsequent research ought to be oriented in the following directions:

- analysis and explanati   of divergences between the results presented in NT 68-Bc-17 and those obtained by Nord-Aviation using a similar configuration;
- extension of the findings from fixed-point to translation;
- increase of disk power and study of the effects due to compressibility of the air for strongly motorized rotors (5000 to 1000 kW/m^2);
- transposition of laboratory findings to aircraft rotors;
- analysis of sonic phenomena.

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